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Spatial Disorientation in Flight : Current Problems

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ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Conference Proceedings No.287

SPATIAL DISORIENTATION IN FLIGHT:

CURRENT PROBLEMS

Edited by

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Papers presented at the Aerospace Medical Panel Specialists' Meeting
held in Bodø, Norway, 20–23 May 1980.

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PREFACE

Spatial disorientation in flight is a term that is applied to a variety of incidents and accidents in which the aviator fails to perceive correctly aircraft attitude, position or motion. The limitations of man's sensory mechanisms and the disturbances of information processing that are responsible for the perceptual errors that characterise spatial disorientation in flight are, by and large, recognised and understood. Over the years, much has been done to overcome these difficulties, primarily, by the provision of instruments which carry symbolic visual cues from which the pilot can determine his orientation and control of his aircraft when external visual cues are inadequate or ambiguous. Yet despite these advances, incidents still occur in which control of the aircraft is lost or is inappropriate because of a perceptual error.

Disorientation features as the principal cause of some 5–10% of major accidents to military aircraft, though this figure is, almost certainly, an underestimate of the proportion of accidents in which the pilot suffered from spatial disorientation according to the definition given above. There is a tendency for those responsible for the identification of the cause of an accident to use the term 'disorientation' only in those circumstances where the pilot suffered, or was thought to have suffered, from an illusory perception of the type that feature prominently in aeromedical texts and which we might call the 'grand vestibular illusions'. Incidents in which the aviator simply failed to perceive a change in aircraft attitude, position or motion, because of, say, a limitation of attentional mechanisms, are more likely to be attributed to the factor responsible for the lapse of attention, and the presence of disorientation as an essential causal element ignored.

The importance of spatial disorientation, as either a principal or contributory cause of aircraft accidents or of incidents which impair operational efficiency, is well recognised by the Aerospace Medical Panel (AMP) of AGARD. The topic featured in a Specialist Meeting of the Panel held in September 1971 and six years have elapsed since the Working Group on 'Orientation/Disorientation Training of Flying Personnel' reported their findings. In the intervening years there have been developments and changes in operational roles, in aircraft instrumentation, and in aircrew training which are likely to have had an impact on the aetiology and incidence of spatial disorientation in flight. The AMP, therefore, considered it to be timely that the topic should again be discussed, so that there could be a wider dissemination of specialist knowledge, not only of contemporary problems and causal mechanisms but also of the measures that are available to minimise the loss of life and aircraft because of spatial disorientation.

A.J.Benson

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EVALUATION TECHNIQUE DE LA SESSION.
par

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Introduction.

Les communications qui ont été présentées à cette session B du 36ème Meeting du Panel de Médecine Aérospatiale de l'AGARD (Bodø 20-23 Mai 1980), ont intéressé les différents aspects médico-physiologiques de la désorientation spatiale en vol.

Conclusions et recommandations.

Les différents exposés, comme les discussions qui les ont accompagnés, permettent de mieux apprécier les orientations qui peuvent être proposées dans l'avenir.

1. L'étude des mécanismes pathologiques de la désorientation spatiale fait intervenir diverses disciplines de la physiologie et de la médecine aéronautique (ophtalmologie -Otologie - psychologie).

   Mais elle nécessite aussi une excellente connaissance de certains phénomènes physiques dont l'expression mathématique peut faciliter l'approche des recherches.

2. La mise en évidence et les moyens d'étude des manifestations aéronautiques de la désorientation peuvent bénéficier de questionnaires, à condition qu'ils soient sérieusement préparés et qu'ils s'adressent à des navigants dont les activités opérationnelles peuvent être différentes(élèves pilotes ; pilotes de chasse ; pilotes d'hélicoptères).

   Les enquêtes d'accidents aériens doivent être très minutieuses et approfondies. Elles doivent comporter, chaque fois que cela est possible, l'étude des conversations enregistrées entre les pilotes ou avec la tour de contrôle. Elles sont utilement comparées avec les résultats de "l'interview" du navigant, réalisée après un vol où il aura été victime de phénomènes de désorientation.

3. Les conséquences opérationnelles des incidents et des accidents liés à cette désorientation spatiale méritent d'être relevées systématiquement dans des études statistiques.

   Leurs incidences chez les pilotes d'hélicoptères paraissent très importantes (1/3 des accidents au Royaume Uni), et sont souvent très graves (décès très fréquents).

   Parmi les causes opérationnelles de désorientation, les illusions visuelles sont particulièrement dangereuses dans les approches au cours des atterrissages.

   L'avènement prochain des procédés d'information visuelle électronique, doit faciliter la navigation en réduisant les erreurs sensorielles.

   Le choix et la couleur des informations alphanumériques ou analogiques méritent une attention toute particulière pour accroître l'efficacité de ces procédés.

4. La prévention de la désorientation spatiale doit s'exercer lors des expertises médicales par des examens approfondis des fonctions visuelles et vestibulaires, utilisant les ressources des techniques les plus différenciées.

   Les déséquilibres neuro-végétatifs doivent être considérés comme des causes d'inaptitude.

   Mais cette prévention doit aussi comporter un ensemble de mesures théoriques et pratiques qui devraient permettre aux futurs pilotes de prendre conscience de l'existence et de la gravité des phénomènes de désorientation, mais aussi de maitriser leurs effets afin de maintenir la sécurité du vol.

   L'accord semble s'être fait sur la nécessité :

   - d'une instruction aéro-médicale dispensée sous forme d'exposés et de films.
   - de démonstrations pratiques avec des appareillages (comme ceux du Docteur BENSON au Royaume Uni et du Docteur BERRY aux U.S.A.) qui, sans être de véritables simulateurs de vol, permettent de faire apparaitre les illusions modifiant l'attitude et perturbant l'appréciation des déplacements, et ce en faisant exécuter au pilote certaines manoeuvres voisines de celles qui sont réalisées en vol.

     Ces démonstrations intéressent tout particulièrement les élèves pilotes mais elles peuvent aussi être renouvelées à des intervalles réguliers dans la carrière d'un navigant ou lorsque ce dernier doit exercer ses activités sur un aéronef de conception différente de celui qu'il utilisait auparavant.
   - des vols "expérimentaux" où il est possible de démontrer la réalité, et les dangers pour la sécurité de la navigation, des phénomènes de désorientation dans diverses conditions aéronautiques.

     Cette pratique parait toutefois difficile à réaliser systématiquement et doit être réservée aux cas limites.

   Ce véritable "training" aéro-médical est déjà réalisé dans plusieurs nations et est fort bien accepté des pilotes qui ont rapidement compris son intérêt.

En conclusion, cette session a démontré que nos connaissances sur les mécanismes physio-pathologiques de la désorientation spatiale méritent d'être approfondies et que les études doivent être poursuivies.

Mais dès maintenant il est possible d'agir avec efficacité pour prévenir les méfaits des diverses illusions sensorielles grâce à une instruction aéro-médicale des pilotes et aussi en utilisant des

appareillages appropriés dont le perfectionnement est encore souhaitable.

LES MECANISMES PHYSIOLOGIQUES DE LA DESORIENTATION SPATIALE D'ORIGINE NON VISUELLE
par

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RESUME

L'orientation spatiale fait intervenir l'intégration complexe de données émanant de nombreux récepteurs. Dans la plupart des cas une désorientation apparaît lorsque le système visuel, qui joue le rôle principal ne peut plus remplir son rôle et que les autres systèmes sont sollicités par un environnement gravito-inertiel inhabituel. Les réactions déclenchées par les accélérations linéaires et radiales, puis par les accélérations angulaires sont passées en revue. Dans un troisième temps les facteurs modifiant l'intensité de ces réactions sont rappelés, ce qui permet d'insister sur le concept de dominance visuelle et de suppression vestibulaire, qui est à l'origine de moyens essentiels de la prévention de la désorientation spatiale en vol : nécessité d'une formation aéro-médicale du personnel navigant, importance particulière de la présentation visuelle des informations nécessaires au pilotage, et entraînement répété au vol en formation et au vol sans visibilité.

On sait depuis les débuts de l'aviation qu'un pilote privé de références visuelles n'arrive pas à maintenir son avion en ligne de vol correcte. C'est pour suppléer aux insuffisances du système d'orientation spatiale de l'organisme au cours du vol sans visibilité ou par mauvaise visibilité que divers instruments de bord, tels que l'horizon artificiel ou l'indicateur de virage, ont été mis au point. Des accidents continuent néanmoins à se produire en raison du caractère irrésistible de certaines illusions sensorielles, qui entraînent des sensations erronées de position spatiale du corps, donc de l'avion. D'après des statistiques récentes, les accidents attribuables à cette désorientation spatiale, représentent environ 6 % de la totalité des accidents graves et 10 à 15 % des accidents mortels.

L'orientation spatiale, comme l'équilibre postural et la locomotion, repose sur l'intégration de données provenant des appareils visuel, vestibulaire, kinesthésique, tactile et auditif. Parmi ceux-ci l'appareil visuel est de loin le plus important. Le système vestibulaire, qui assure en conditions normales la stabilisation du système visuel et l'équilibre postural, intervient comme système de remplacement lorsque les références visuelles font défaut. La même fonction est assurée par les systèmes kinesthésique, tactile et auditif. Mais la précision et la sécurité de l'orientation ainsi fournie sont loin d'atteindre celles assurées par la vision. C'est pourquoi la désorientation spatiale apparaît lorsque le pilote, privé de références extérieures, est dans l'incapacité de voir ses instruments de bord, ou est incapable d'interpréter les informations qu'il en reçoit ou de croire en elles.

1°) Réactions déclenchées par les accélérations linéaires et radiales.

Au cours du vol, l'organisme est soumis, du fait des mouvements de l'avion ou du véhicule spatial, à un ensemble de forces (force d'inertie, force de pesanteur...), qui se composent en une résultante changeante qui équivaut pour lui à une variation en intensité ou en direction (ou les deux à la fois) du vecteur champ de pesanteur terrestre. Il s'agit là d'un phénomène spécifique et nouveau, car l'homme est habitué à vivre dans le champ de pesanteur terrestre, pratiquement uniforme pour lui, et que le système vestibulaire est incapable de faire la distinction entre force de gravité et force d'inertie.

Cette variation apparente du champ de pesanteur agit de manière différente sur les divers mécanismes impliqués dans l'orientation spatiale, la posture et les mouvements.

- L'action la plus immédiate se fait sentir sur le seul récepteur de l'organisme qui soit spécifique du vecteur champ de pesanteur : l'appareil otolithique.
- Une action directe se fera également sentir par d'autres récepteurs, bien qu'ils ne soient pas spécifiques de la pesanteur :
  - les fuseaux neuro-musculaires et les organes tendineux de GOLGI. La résultante des forces d'inertie et de pesanteur, en augmentant ou en diminuant l'étirement des muscles, en particulier des muscles extenseurs du cou, de la tête, du tronc et des membres, provoque des modifications des contractions réflexes destinées à maintenir le corps dans des relations spatiales normales avec la verticale.
  - les récepteurs proprioceptifs cutanés. La force de pesanteur fait naître des sensations de pression et de contact dont la distribution nous renseigne sur la position du corps par rapport au vecteur champ de pesanteur. La résultante des forces d'inertie et de pesanteur en modifiant la distribution normale modifiera aussi les renseignements émanant des récepteurs cutanés.
- Les autres récepteurs sont théoriquement indépendants du champ de pesanteur, il s'agit de la vision, des canaux semi-circulaires et des récepteurs articulaires. Ils ne subiront qu'une action indirecte.

Cette action directe ou indirecte de la variation apparente du vecteur champ de pesanteur va entraîner quatre conséquences :

1.1. - Mauvaise interprétation de la position du corps dans l'espace.

1.1.1. Confusion entre verticale vraie et résultante gravito-inertielle.

La sensation consciente de la position du corps par rapport à la verticale de référence se fait par rapport à la résultante des forces, dont la direction peut s'écarter considérablement de la verticale vraie.

Parmi les illusions qui se rattachent à ce mécanisme se trouvent les illusions somatograviques de cabré, d'inversion, de montée, de descente ou d'inclinaison en virage ou à la sortie d'un virage.

a - illusion somatogravique de cabré

L'illusion de cabré au cours du décollage, ou de la remise des gaz lors d'une approche ratée, la nuit ou par mauvaise visibilité, s'observe dans le cas des avions à hautes performances, ou au cours des décollages assistés par fusée ou catapultés. La résultante de l'accélération linéaire + G_x et de l'accélération de la pesanteur est inclinée en bas et en avant. Le système otolithique, et les récepteurs cutanés et kinesthésiques sont stimulés de la même façon que par une bascule du corps en arrière, et le pilote a l'illusion que l'avion se cabre. Il peut alors être tenté de pousser le manche pour remettre l'avion en vol horizontal. L'avion viendrait alors percuter le sol, presque à plat, à quelques kilomètres de l'extrêmité de la piste.

b - illusion somatogravique d'inversion

Cette illusion s'observe pendant le rétablissement succédant à une montée rapide effectuée avec un avion à haute performance par mauvaise visibilité. Il existe dans ce cas une combinaison de l'accélération de la pesanteur, de l'accélération tangentielle + G_x (l'avion prend de la vitesse pendant le rétablissement) et de l'accélération radiale - G_z (l'avion suit une trajectoire curviligne). La sensation est celle d'une bascule en arrière, qui peut aller jusqu'à l'illusion de se trouver en position inversée.

c - illusions somatograviques de montée, de descente ou d'inclinaison

Ces illusions ont pour origine le système otolithique et les récepteurs cutanés et kinestésiques. Au cours d'un virage serré, le pilote est plaqué sur son siège. En l'absence de repères visuels extérieurs, il assimile ses sensations à celle d'une montée (ou de looping). En sortie de virage, la réduction des forces plaquant le pilote sur son siège, et stimulant les macules, peut être assimilée à la sensation de légèreté qui accompagne une descente rapide. Lors d'un virage de longue durée comportant une glissade ou dérapage, non seulement les cupules sont revenues à leur position de repos, mais en outre la résultante des forces gravito-inertielles n'est plus perpendiculaire au plancher de l'avion. Le pilote a la sensation d'être incliné, en sens inverse de l'inclinaison normale de l'avion dans le cas de dérapage, dans le même sens en cas de glissade.

Il est également possible que les illusions très convaincantes de roulis ou de tangage qui apparaissent brusquement lorsqu'un pilote tourne la tête au cours d'un virage de longue durée à vitesse constante ne soient pas uniquement dues à la stimulation des canaux semi-circulaires (phénomène de Coriolis). Il n'est pas exclu que les variations rapides en intensité et en direction de la résultante gravito-inertielle qui interviennent dans les avions rapides et très manoeuvrables de la génération actuelle soient à l'origine de ces phénomènes souvent désignés sous le terme d'effet de G excessif ou d'effet de G anormal qui releveraient donc d'un mécanisme otolithique également.

1.1.2. Non perception d'un changement de position

Pour qu'un changement de position du corps soit perçu il faut qu'il soit supra-liminaire pour les organes otolithiques. Leurs seuils de fonctionnement sont très bas. Ils sont capables de détecter un changement de 1,5° de la direction d'une accélération linéaire. Chez des sujets sensibles, une accélération de 0,02 m/s^2 (soit 0,002 g) peut être perçue, dans le plan horizontal et de 0,1 m/s^2 (0,01 g) dans le plan vertical, à condition de durer environ 5 s.

Mais lorsque les mouvements sont lents, il faut une certaine amplitude pour qu'ils puissent être perçus. Ainsi, si l'on bascule très lentement un sujet assis, les yeux bandés, il ne percevra un changement de sa position par rapport à l'horizontale que si le mouvement atteint une amplitude de 24° dans le plan vertical et de 10° dans le plan frontal.

Les sensations erronées d'inclinaison après un mouvement de roulis infra-liminaire suivi d'une correction supra-liminaire (ou inversement) sont des exemples d'illusions rattachées aux caractéristiques de fonctionnement des organes otolithiques. Mais dans ce cas, il est important de remarquer que le mouvement de roulis intervient aussi sur les canaux semi-circulaires. Les illusions d'inclinaison sont donc souvent d'origine mixte, bien que classiquement rattachées aux canaux semi-circulaires seulement.

1.2. - Déclenchement de réflexes posturaux

Lors d'un changement rapide de la résultante des forces d'inertie et de pesanteur il apparaît des mouvements réflexes de la tête, du tronc et des membres, destinés :

- . à faire de la tête une plateforme stable pour les yeux,
- . à maintenir la posture initiale,
- . dans les cas de changement brutal à protéger le corps en cas de chute.

Ces mouvements peuvent éventuellement être à l'origine d'actions défavorables sur les commandes de l'avion.

1.3. - Déclenchement de réflexes vestibulo-oculaires

Ces réflexes sont destinés à la stabilisation de l'image rétinienne. Ils peuvent se subdiviser en trois catégories, qui peuvent se combiner :

- mouvement de bascule des yeux vers le bas lors d'une accélération linéaire verticale dirigée vers le haut, et inversement,
- mouvement latéral des yeux lors d'une accélération linéaire horizontale côté-côté, en sens inverse de la direction de l'accélération,
- mouvement de rotation des yeux autour de leur axe antéro-postérieur, lors d'un mouvement de bascule de la tête ou de la résultante gravito-inertielle dans le plan frontal. Cette rotation se fait en sens inverse du mouvement de bascule, mais, du fait de sa faible amplitude, ne joue pas de rôle compensateur.

Ces mouvements réflexes des yeux sont à l'origine d'illusions classées sous le terme d'illusions oculograviques, telles que l'illusion oculogravique de cabré, l'illusion oculogravique de piqué et l'illusion oculoagravique.

a - illusion oculogravique de cabré

Cette illusion apparaît au cours d'une accélération + G_z brutale provoquée par une turbulence ou le rétablissement après une descente rapide. La stimulation du système otolithique provoque par voie réflexe une bascule des yeux vers le haut. Le déplacement apparent du tableau de bord est interprété comme le résultat d'un mouvement de cabré de l'avion, que le pilote est tenté de corriger par un mouvement de piquer du manche.

b - illusion oculogravique de piqué et illusion oculoagravique

Cette illusion est le symétrique de la précédente. Elle apparaît aussi au moment du passage en absence de pesanteur (ou en pesanteur très réduite). Ce réflexe à point de départ otolithique consiste en une bascule des yeux vers le haut. Le tableau de bord semble se déplacer vers le bas, ce qui peut être interprêté, en l'absence de repères extérieurs, comme un mouvement de piqué.

1.4. - Déclenchement de réactions vestibulo-végétatives

Il s'agit d'un ensemble de réflexe neuro-végétatifs destinés à préparer l'organisme aux effets des forces d'inertie, notamment en ce qui concerne le système cardio-vasculaire. Dans le cas d'une stimulation trop intense ou trop prolongée les réflexes autonomes déclenchés peuvent aboutir à l'apparition du mal des transports.

2°) Réactions déclenchées par les accélérations angulaires.

Les mouvements de l'avion ou du véhicule spatial provoquent aussi l'apparition d'accélérations angulaires. Ces accélérations angulaires agissent de façon primordiale sur les canaux semi-circulaires, récepteurs spécifiques de ces accélérations, et entraînant des conséquences similaires à celles de l'action des accélérations linéaires sur l'appareil otolithique.

2.1. - Sensation de rotation ou d'absence de rotation.

2.1.1. Illusions de rotation entraînées par des stimulations supra-liminaires.

La stimulation des canaux semi-circulaires par une accélération angulaire ayant une intensité et une durée suffisantes, entraîne une sensation de rotation dans le plan du canal stimulé et dans le sens de l'accélération. Il est important de se rappeler qu'à une rotation à vitesse constante correspond une accélération angulaire nulle, donc une absence de sensation de rotation, de sorte qu'à l'arrêt d'une rotation (ce qui obligatoirement correspond à une accélération angulaire en sens inverse de la rotation), il apparaît une sensation de rotation dans le sens inverse de l'accélération, donc en sens inverse de la rotation réelle

Les illusions rattachées à ce mécanisme de fonctionnement des canaux semi-circulaires sont dites somatogyrales. Elles peuvent s'observer, soit au cours d'un virage, d'une vrille, ou d'une spirale, soit lors d'une combinaison de deux accélérations angulaires ou d'une accélération angulaire et d'une accélération radiale.

a - virage :

Lors d'un virage correctement incliné, à vitesse constante, et de longue durée, les cupules des canaux semi-circulaires ont le temps de revenir à leur position de repos. Le pilote n'a plus la sensation de tourner et a l'illusion de voler en ligne droite, car seule demeure la stimulation du système otolithique, des propriocepteurs somatiques, et des récepteurs cutanés par la résultante des forces gravito-inertielles, qui est perpendiculaire au plancher de l'avion.

A la sortie d'un virage correctement incliné de longue durée (tel un virage d'attente) le pilote a la sensation d'être incliné en sens inverse alors que son avion est horizontal, les cupules étant défléchies alors qu'elles étaient au repos pendant le virage.

b - vrille :

Lorsqu'une vrille se déroule de nuit ou par mauvais temps, et qu'elle dure plus de 5 secondes, une situation extrêmement dangereuse peut s'établir, qui lui a fait donner le nom de vrille à mort. A l'absence de références extérieures s'ajoute le fait que l'observation des instruments de bord est rendue diffi-

cile par le nystagmus provoqué par la rotation. La succession des évènements au cours d'une telle vrille est la suivante. La vrille s'est prolongée suffisamment pour que les cupules de canaux semi-circulaires soient revenues à leur position de repos. La sensation de rotation est alors absente.

Le pilote exécute les manoeuvres de sortie de vrille. La rotation de l'avion cesse. Les cupules des canaux semi-circulaires sont défléchies, et une sensation de rotation en sens inverse de la précédente apparaît, faisant croire à l'établissement d'une vrille en sens inverse. Le pilote exécute les manoeuvres de sortie de cette vrille imaginaire. Il repart en vrille dans le même sens qu'auparavant.

c - spirale :

Contrairement à ce qui se passe dans la vrille, l'avion vole : il descend rapidement en virant. La vitesse de virage étant constante, le pilote cesse au bout d'un certain temps de percevoir qu'il tourne, et ne se rend compte que de sa perte d'altitude. Pour arrêter sa descente il est tenté de tirer sur le manche et de pousser la manette des gaz. Cette manoeuvre n'aboutirait qu'à resserrer la spirale. Pour l'arrêter, il faudrait que le pilote remette d'abord à l'horizontale les plans de son appareil. Mais il a alors l'illusion de tourner en sens inverse de la spirale initiale. L'arrêt de cette spirale à mort ne peut, comme dans le cas de la vrille à mort, être obtenue que grâce à de bonnes références extérieures, ou en l'absence de celles-ci, par une confiance totale dans les instruments de bord et la conviction d'être en présence d'une illusion sensorielle.

d - effet de Coriolis :

Il s'agit d'une des illusions les plus dangereuses. Elle apparaît lorsque les cupules d'une paire de canaux semi-circulaires sont revenues à leur position de repos au cours d'un virage à vitesse constante et que le sujet exécute un mouvement de la tête dans un plan perpendiculaire au plan de rotation. Les canaux semi-circulaires au repos sortent du plan de rotation et sont de nouveaux excités, alors qu'une deuxième paire de canaux entre dans le plan de rotation et se trouve excitée également. Ce phénomène entraîne des sensations puissantes mais erronées de rotation. De telles illusions de rotation dans un plan résultant où il n'existe en réalité aucun mouvement angulaire peuvent être dangereuses si elles apparaîssent près du sol en raison de l'action correctrice réflexe qu'exerce aussitôt le pilote sur les commandes de son avion.

2.1.2. Illusions entraînées par des stimulations infra-liminaires

La réponse à une rotation est maximale pour un canal lorsque celui-ci est situé dans le plan du mouvement. Les canaux horizontaux sont les plus sensibles. Le seuil moyen d'accélération angulaire détectable par ces canaux est de $0{,}14°/s^2$. (Le seuil le plus bas qui ait été mesuré sur un sujet humain a été de $0{,}05°/s^2$.). Pour les canaux verticaux le seuil est d'environ $0{,}5°/s^2$. Les limites de perception d'une accélération angulaire dépendent non seulement de la valeur de cette accélération, mais aussi du temps pendant lequel elle est appliquée. Pour qu'une accélération angulaire soit perçue il faut que le produit de son intensité par son temps d'application soit égal à 2,5. Cette loi, dite loi de MULDER s'exprime par l'équation simple :

$$\alpha . t \quad = \quad 2{,}5\ ° / s$$

Autrement dit, plus une accélération angulaire est faible (jusqu'à un certain seuil), plus son temps d'application doit être long. D'après l'équation ci-dessus, une accélération angulaire de $5\ °/s^2$ durant 0,5 s *sera perçue mais pour qu'une accélération de* $0{,}25\ °/s^2$ *soit perçue il faut qu'elle dure 10 s, et 17 s* pour $0{,}14°\ /s^2$.

Il est également bon de rappeler que les seuils sont différents selon que l'on envisage la perception du mouvement, l'apparition du nystagmus ou l'apparition de l'illusion oculogyre.

Ce temps peut être calculé grâce à l'équation de deuxième ordre d'un pendule de torsion amorti représentatif de la cupule, plus complexe que l'équation précédente ;

$$\alpha\ (t) = \frac{d^2\ x}{dt^2} + 2\ \gamma\ \omega_n \frac{dx}{dt} + \omega_n^{\ 2}\ x$$

Un mouvement n'entraînant qu'une accélération angulaire infra liminaire ne sera pas perçu et pourra être à l'origine de sensations d'inclinaison.

Ces illusions d'inclinaison en roulis (inclinaison latérale), sont parmi les plus fréquemment observées. Ce sont des sensations très puissantes, le pilote se penchant réellement, ou même s'appuyant sur une paroi latérale de la cabine pour "reprendre son équilibre".

Elles reconnaissent deux mécanismes :

- inclinaison de l'avion avec une vitesse de roulis infra-liminaire, suivie d'une manoeuvre de redressement supra-liminaire. Seul le mouvement de redressement est perçu et entraîne les réflexes et la sensation d'être incliné alors que l'appareil est horizontal.
- inclinaison de l'avion avec une vitesse de roulis supra-liminaire et redressement avec une vitesse de roulis infra-liminaire.

2.2. - Déclenchement de réflexes posturaux :

Ces réflexes ont les mêmes buts que dans le cas des réflexes déclenchés par la stimulation de l'appareil otolithique. Il s'agit principalement d'une déviation lente des membres, en sens inverse de l'accélération angulaire, qui dure aussi longtemps que les cupules sont déviées.

2.3. - Déclenchement de réflexes vestibulo-oculaires :

Comme dans le cas des réflexes vestibulo-oculaires otolithiques, ces réflexes sont destinés à stabiliser l'image rétinienne. La stimulation d'un canal semi-circulaire provoque une déviation lente des yeux en sens inverse de la direction de l'accélération. Si l'accélération angulaire se maintient un temps suffisant à ce mouvement compensateur succède un nystagmus.

Ces réflexes sont à l'origine des illusions oculogyrales.

. illusions oculogyrales

Il s'agit du déplacement apparent d'un objet placé en face d'un sujet qui subit une accélération angulaire. L'illusion est facilement mise en évidence en faisant tourner dans l'obscurité un sujet assis sur un fauteuil tournant et en lui demandant de fixer un point lumineux qui lui est solidaire. Pendant que le fauteuil tourne, la lumière semble se déplacer dans le même sens que la rotation, avec une amplitude qui peut atteindre 30° d'arc. Après l'arrêt, elle semble se déplacer, par saccades, dans l'autre sens, et avec une amplitude qui peut atteindre 60° d'arc.

2.4. - Déclenchement de réflexes vestibulo-végétatifs :

Il s'agit d'un ensemble de réactions sympathiques et para-sympathiques, retrouvé dans le tableau du mal des transports, et dont l'étendue s'explique par le fait que le système vestibulaire est le système sensoriel dont les projections se distribuent le plus largement dans le système nerveux central.

3°) Facteurs modifiant l'intensité des réflexes vestibulaires

3.1. - Etat d'éveil :

L'état d'éveil d'un sujet modifie profondément ses reflexes vestibulaires en qualité et en quantité. Un état d'hyper-éveil s'accompagne d'une exagération des réflexes. Inversement, les réflexes vestibulaires sont diminués chez un sujet en état de relaxation (ils peuvent même disparaître). Ces inter-actions, explicables par la participation du cortex et de la formation réticulée aux voies vestibulaires sont d'une grande importance dans l'apparition des illusions sensorielles ou du mal de l'air. Les facteurs dynamiques nécessaires à l'apparition d'une illusion sensorielle n'entraîneront pas systématiquement et nécessairement cette illusion. Un pilote soumis à ces facteurs risquera davantage de subir une désorientation spatiale s'il est très occupé par un travail de navigation, ou fatigué, ou anxieux, ou encore préoccupé par un stress psychique tel que des problèmes familiaux, conditions qui aboutissent à un état d'hyper-réveil.

Certaines illusions d'inclinaison reconnaissent ce mécanisme, le seuil élevé au cours d'un état d'éveil médiocre peut être brusquement abaissé par l'établissement d'un état d'éveil intense.

3.2. - Accoutumance :

Il est bien connu que la plupart des sujets s'adaptent aux accélérations qui provoquent le mal de mer. Il en est de même pour le mal de l'air ou de l'espace. Il est également prouvé que des expositions répétées à des accélérations angulaires entraînent une diminution de la réponse nystagmique. Il existe donc une accoutumance aux accélérations, qui diminue l'intensité des réflexes vestibulaires.

3.3. - Dominance visuelle et suppression vestibulaire :

En dehors de l'accoutumance qui peut être acquise passivement, l'entraînement au vol en formation ou au vol sans visibilité permet d'acquérir toutes les informations nécessaires à l'orientation spatiale par la vue seule. C'est ce que l'on appelle la dominance visuelle, qui s'accompagne d'une diminution, voire de la suppression de la prise en compte des autres informations en particulier vestibulaires. Dominance visuelle et suppression vestibulaire ne peuvent être par la suite conservées que par la répétition des exercices.

Au cours du vol par bonne visibilité l'orientation spatiale ne pose habituellement pas de problème. Les références extérieures : le ciel et la terre, sont suffisamment puissantes pour que l'on sache immédiatement dans quelle position se trouve l'avion. Lorsque la visibilité est mauvaise - vol de nuit ou par mauvais temps - le pilote n'a à sa disposition, pour s'orienter dans l'espace, que les instruments de bord.

Ce facteur prend une grande importance dans l'étude de la présentation des informations, qu'il s'agisse des dispositifs de pilotage "tête basse" ou "tête haute". Il est nécessaire que les informations renseignant sur la position de l'avion dans l'espace soient le plus convaincantes possible rendant ainsi leur acquisition la plus rapide possible. (la vision périphérique est particulièrement importante dans ce domaine).

Cette notion de rapidité est spécialement importante dans le cas du vol en formation serrée. En effet chaque équipier doit suivre son leader et son travail aérien consiste à maintenir sa place dans la formation, par rapport au leader et aux autres équipiers. Deux facteurs sont importants à considérer :

- obligé de ne guère quitter des yeux le leader, l'équipier ne dispose que de très peu de temps pour jeter un coup d'oeil sur ses instruments de bord,
- l'avion du leader ne se comporte en aucune façon comme un indicateur d'assiette.

Si la formation vole à basse altitude et pénètre brutalement dans les nuages, les équipiers qui perdent de vue leur leader peuvent se trouver complètement désorientés et ne pas avoir le temps d'acquérir les informations nécessaires à partir de leur tableau de bord avant de percuter le sol.

CONCLUSIONS

Cette revue des mécanismes physiologiques de la désorientation spatiale non visuelle a permis de classer les différentes illusions d'origine principalement vestibulaire. Elle permet aussi de bien comprendre les points essentiels de la prévention des accidents que peuvent entraîner ces illusions.

- nécessité d'une bonne connaissance par le personnel navigant des mécanismes physiologiques des illusions sensorielles afin de les dominer. L'enseignement et l'entraînement médico-aéronautique des équipages sur simulateurs est donc d'une grande importance.

- nécessité d'une information visuelle puissante de la position de l'avion lors du vol sans visibilité ou par mauvaise visibilité, et d'une étude ergonomique sérieuse du poste de pilotage évitant les rotations importantes de la tête au cours des phases de vol critiques.

- nécessité de l'entretien de la dominance visuelle et de la suppression vestibulaire par la répétition des vols en formation serrée et aux instruments.

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DISCUSSION

BENSON

Would you care to comment on problems of spatial disorientation associated with the use of Head-Up Displays (HUD)? In the Royal Air Force we have had a number of incidents of disorientation associated with failure of the HUD, particularly in those aircraft in which the Head-Down instruments (HDD) have been relegated to a stand-by role and hence are small and are not configured in a conventional manner. Thus on transfer from the HUD to the HDD the pilot had greater difficulty in establishing aircraft orientation than if the HDD comprised a conventional instrument panel.

AUTHOR'S REPLY

We have considerable experience of Head-Up Displays and work is in progress at CERMA concerning the visual problems of HUDs. However, I am not aware of any work related to vestibular problems associated with the use of HUDs or of any specific association of them with spatial disorientation.

AN UPDATE OF FINDINGS REGARDING SPATIAL DISORIENTATION IN FLIGHT A RECONSIDERATION OF UNDERLYING MECHANISMS

by

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The anatomical foundations, physiological mechanisms and mental functions known to influence spatial orientation on earth and in flight are reviewed in light of past experience and empirical findings. The effects of flight environment on visual, vestibular and kinaesthetic cues as well as on mental functions, able to induce perceptual errors conducive to spatial disorientation are reconsidered with a view of identifying the theories accounting for disorientation incidents and accidents in flight.The state-of the-art of the theories can be summarized as follows: although the basic physiological mechanisms of spatial orientation are well understood, conceptual models of their interactions are not conclusive; none of the current models and theories is able to encompass adequately all the factors involved in spatial disorientation; arousal theories may provide a useful tool to make distinctions between perceptual errors and aetiological factors in disorientation incidents and accidents.

Anatomical foundations of spatial orientation

The spatially coordinated behaviour of man depends on the integration of signals from many sensory receptors. Receptors are grouped together in specialized organs, like the eye and the vestibular apparatus of inner ear, or dispersed in the body, like the mechanoreceptors in the skin, joint capsules, ligaments, muscles, tendon and visceral organs. While the eyes provide a three-dimensional scheme of the immediate environment, the otoliths and the cupulae of the statokinetic labyrinth supply information about linear and angular movements of the head, and the variety of mechanoreceptors generally dispersed in the body are a source of information for kinaesthetic judgements (Sherrington,1906). By aircrew usage, all non-visual sensations contributing to orientation in flight are referred to as the "seat of the pants". Last but not least, the sense of hearing, clearly of limited importance for spatial orientation on earth, may prove useful during flight operations (Benson,1978).

Vestibular nystagmus in both its phases is basically controlled by subcortical centres. The vestibular nuclei discharge via the medial longitudinal fasciculus and some other bypath to the oculomotor nuclei. Vestibular influences are mediated by the lateral and medial vestibulospinal tracts to the spinal cord through the reticular formation, while somatosensory spinal influences impinge on vestibular nuclei and the cerebellum. Impulses from the superior and medial nuclei go into the cerebellum, whereas the lateral vestibular nucleus receives cerebellovestibular fibers. The medial vestibular nucleus has connections with the reticular gray of the brain-stem and through this with the efferent nucleus of the vagus nerve.

There is no defined tract or pathway from the vestibular nuclei to the thalamus or to cerebral cortex, and there is no known central localisation for the perception of vestibular impulses. However, a primary vestibular projection was discovered in the parietal lobe and is presumably responsible for integrated perception of body position and movements (Frederickson,1975). Central visual pathways terminate in the occipital cortex. Long association pathways link the visual cortex with the temporal lobe and the association areas. Perceptual mechanisms are notably related to the brain-stem reticular formation and to the system of diffuse thalamic projections, both interacting with the cerebral cortex (Moruzzi&Magoun,1949).

Physiological mechanisms involved in spatial orientation

A consensus has built up over the primary importance of vision in spatial orientation. L'appareil visuel est le chef de file (Blanc,1978). La vision corrige les données provenant des autres sources d'information (Chevaleraud,1978).

Postural and vestibuloocular reflexes stabilise the retinal image. Unless the retinal image is reasonably stable and fixation of the eye relative to the observed object is preserved for 100 sec or so, then visual acuity is impaired (Benson,1978). However, the impairment of visual target acquisition and tracking performance could in part be attributed to involuntary movements consequent upon stimulation of the vestibuloocular reflex by head turning movements (Barnes&Sommerville,1978).

All over recent years physiological evidence has been accumulating with respect to the relevance of vestibular-visual interactions.

Stimulation by high-level rotary deceleration produced positive accomodation or a pseudo-myopia and this could be the result of a vestibular-ocular accomodation reflex (Clark,1975). Arguments were presented relating this accomodative response to the utricles (Markham,1977).

The ability to judge visual cues depends on the interplay of information from the centres responsible for the voluntary control of eye movements and information from those indicating image movements on the retina.

A model providing information about pilot control performance with visual and motion cues and predicting the change in scanning behaviour was developed (Curry, 1976). Monocular peripheral vision as a factor of flight safety was assessed (Kochhar,1978). The significance of depth perception in aviation was reviewed (Manent,1978). The minimum set of visual image cues sufficient for spatial orientation during aircraft landing approaches was isolated (Eisele,1976). Whenever the detectability of motion is enhanced,i.e., the threshold for the detection of motion is lowered, the effectiveness of movement parallax as a cue to depth is increased (Hell,1977).

The role of gravitation is essentially one of maintaining orientation.

The vestibular system as a system sensing extrasubjective gravitational space constants, was regarded as most important in the formation of visual concepts of space coordinates as reflected by the objective characteristics of oculomotor reactions (Kurashvili,1974). However, vestibular senses alone cannot provide meaningful postural orientation to simulated or actual gravity of a magnitude below that of earth's gravity (Shillinger, 1973).

100 years ago, Mach concluded that the adequate stimulus for the semicircular canals must be pressure, and that the sustained endolymph flow theory of Breuer is erroneous.

Von Holst put forward the shearing theory of the otolith stimulation, but more recently Japanese authors have given experimenatl support to the old classical pull and press theory of Quix and Magnus.

Both organs, utricle and canal, are dynamic and static receptors (Howard, 1966). There is physiological evidence of the acceptability of the Flourens and Ewald's laws relating to the integrated pattern of smooth pursuit eye movements interspersed with quick repositioning saccades, termed as nystagmus.

While activity detection thresholds can be determined for the semicircular canals by the use of the so called Barany tests amounting to behavioural criteria like feelings of rotation, nystagmus, oculogyral illusions, this proves to be difficult for the detection of the activity thresholds of the otolith organs.

There are more obstacles to determining otolithic enhancement of behavioural performance than to determining otolith-based decrements in performance (Graybiel,1974).

The threshold for the perception of angular acceleration as indicated by the oculogyral illusion was studied by Miller&Graybiel(1974)

The threshold for the detection of a linear acceleration has been found to range from 0.002g to 0.02 g (0.3-0.2 m/sec^2). When the acceleration is applied for less than 5 seconds then the linear velocity must exceed 0.3-0.4 m/sec for the motion to be perceived.(Benson,1978).

For angular movements of short duration (not greater than about 5 seconds) the angular velocity must exceed 0.2-0.8^o/sec (3.5-140 mrad/sec) for the motion to be perceived. The threshold for detection of a sustained (more than 10 seconds) angular acceleration ranges from 0.05 to 2.2^o/sec^2 (0.1-38 mrad/sec^2). (Benson,1978).

The overall data from experiments on the detection of roll motion were provided. They suggested synergistic action of the semicircular canals and gravireceptors. The influence of somatosensory stimuli was considered.(Gundry,19770.

The roles of otolith, somatosensory and visual detection mechanisms in determining threshold of perception for periodic linear motion were discussed. The data for frequencies above 1 Hz reflect an unknown mix of visual, otolith and somatosensory influences. (Gundry, 1977).

The threshold response during anoxia was studied . The sensitivity threshold to angular accelerations increased while vestibular stability decreased significantly revealing latent forms of vestibular autonomic instability (Sidelnikov,1975).

The threshold values of Coriolis acceleration were determined during man's rotation with head movements in the sagittal and frontal planes (Solodovnik,1974).

Rotation sensation thresholds for a swing type moving simulator were investigated (Topinga,1975).

The otolith organs resemble accelerometers and must accordingly respond to stress gradient. This means that they will indicate the current direction of support thrust, even in a moving vehicle, rather than some reference direction such as that of gravity (Roberts,1977).

The researchers investigated the responses to intercating sensory input as visual vestibular interactions and apparent intravestibular interactions between canals and otoliths.

An overall survey of the state-of-the-art of the psychophysics of vestibular sensation was performed by Guedry (1974).

A thorough review of the literature of a ten-year program research on vestibular-visual interactions in flight simulators was performed by Clark (1977).

A review of the dynamic behaviour of two oculomotor systems - the vestibular and pursuit reflexes - responsible for the spatial and temporal stabilization of the image of an observed object on the fovea of the retina, and mathematical models adduced in which the contribution of physiological components of the systems can be identified (Benson&Barnes,1977).

The vestibuloocular system was examined from the standpoint of system theory and many characteristics of the eye movements in vestibularly induced nystagmus explained (Schmid,1974).

A solution for optimal subjective orientation based on several sensory modalities was depicted in the form of a flow chart representation (Young,1974).

A mathematical model of the vestibuloocular reflex was suggested (Chun,1977).

Abolition of counterrollreflex was demonstrated after bilateral labyrinthectomy (Smiles,1975).

The vestibuloocular reflex was considered as a medium through which automatic stabilization of the eye relative to inertial space is achieved over the normal range of naturally occurring angular head movements(Jones,1974).

The conditioned suppression of vestibular nystagmus with visual suppression was studied (Guedry,1977)

The influence of peripheral vision on suppression of VOR and visual acuity was investigated by Guedry (1978).

The extent to which inappropriate reflex eye movements of vestibular origin cna be suppressed by visual feedback was investigated. The results implicated that breakdown in the pursuit reflex and in suppression of the VOR occurred over the same frequency band implying similarity of the mechanisms responsible for the suppression and the pursuit (Barnes,1978).

The VOR was studied during simultaneous optokinetic and vestibular stimulations (Lau,1978).

Electrophysiological investigations of the convergence and interactions of afferent signals entering the vestibular system along various sensory channels were considered. The possible contribution of this interaction to the integral activity of the brain and the spatial orientation of the body was discussed (Raytses,1974).

The studies of visual of visual vestibular interactions in the case of linear motion, concerning self-motion perception, modification of the perceived velocity of a visual scene,postural readjustements, contribution of vision during postural perturbation during linear accelerations were reviewed. Suggestive evidence was given that linear acceleration does improve the dynamics of fusion (Berthoz,1977).

Mental functions responsible for spatial orientation

Position and motion perception **depends** on **sensory** input, cybernetic information processing, neural habituation mechanisms and is influenced by learned experience and emotional states. Central control is different for the the various sensory cues relevant to orientation. In the process of becoming aware of object qualities and relations by the way of sense organs, some information is registered by the brain but not perceived. While sensory content is always present in perception, what is perceived is influenced by set and prior experience so that perception is an active processing of the stimuli impinging on the sense organs. La perception est une intégration complexe à l'intérieur de la modalité sensorielle prédominante (Angiboust,1978). A model subsuming a hypothetical neural mechanism which allows x-andy-axis acceleration to be resolved was presented by Benson (1973). A differential equation for describing how the brain compromises between a sensation of rotation about a particular axis derived from the semicircular canals and a sensation of gravity perpendicular to this axis derived from the otolith organs was proposed by Epstein (1977). A model for the perception of dynamic orientation resulting from stimuli involving both the otoliths and the canals was developed by Young (1978).

Some vestibular information, like that from the otoliths, is merely stored in the brain, instrumental in maintaining adequate reflex activity during coordinated action,but not actually perceived. Conversely, vestibularocular reflexes diminishing because of neural habituation can be fully reinstated by computational arousal.

The arousal hypothesis relevant to perception can be traced back to behavioural concepts of Malmo (1959) that propose an optimum level of arousal that produces optimum performance, and deviations from which produce impaired performance. In the context of spatial orientation arousal is used to identify a physiological and psychological state ranging from drowsiness at one extreme, to acute awareness, even panic, at the other, able to modify reflex physiological mechanisms as well as perceptual integration, higher mental functions and well-learned flying habits of pilots with the ultimate result in some disturbances of spatial orientation in flight environment.

Perception in pilots depends on deploying stored knowledge rather than on responding directly to stimuli. Perceptions are suggested to be equivalent to hypotheses in science, since both of them are of predictive nature, are based on limited information, and are subject to the same kind of limits and errors (Gregory,1976). A logic mathematical model was proposed for the visual perception of motion by man (Lebedeva,1975). A comparison of the visual perception of a runway model in pilots and nonpilots during simulated night landing approach was performed. (Mertens,1978). Motion perception and terrain visual cues in air combat simulation were evaluated.(Stark,1976).

Repeated exposure to unnatural patterns of stimuli elicits systematic changes in the response of the central nervous system.

The habituation of practical interest to aviation medicine involves much more than changes in vestibular reactions per se. The various changes in vestibular reactions are, however, intimately involved with various sensory, cognitive, and emotional processes of habituation (Guedry,1971). While repeated exposure to patterns of stimulation with the range of natural experience is ineffectual, it is shown experimentally that repeated exposure to unnatural patterns of movement is associated with systematic changes in response often called habituation. It seems that habituation is not merely long term adaptation to any maintained sensory stimulus but rather a manifestation of a general tencdency in the central nervous system to meet optimization criteria when the need arises.Gonshor & MelvillJones,1973). An historical survey of vestibular habituation experiemnts including the influence of arousal on vestibular responses was performed by Collins (1973).

Disorientation incidents and accidents

Spatial disorientation in flight (SDF) refers to an incorrect self-appraisal of the attitude or motion of the pilot and his aircrfat with respect to the earth.

While all aviators are prone to this psychophysiological phenomenon, an awareness of erroneous sensations seems to be more common in student pilots, particularly during the early phases of instrument flying training (Benson,1978). Conflict of sensory cues is a quite normal, physiological response to particular aircraft motions. The nature and intensity of erroneous sensations, the ease with which orientation conflicts are resolved and the frequency of disorientation incidents range within broad limits.

Occurrences with minor or no aircraft damage, straightforwardly attributed by the pilot to a disorientation experience, are termed incidents; occurrences with serious or write-off aircraft damage including a high proportion of fatalities are termed accidents.

Incidence

Evidence has been accumulating that the early statistics of disorientation incidents are not trustworthy. The dearth of records from the 1940s and 1950s can be attributed to lack of understanding by the pilot for this particular experience or to fear that it might be interpreted as a lack of fitness.

In analysing the chain of events which leads to an aircraft accident the investigator is rarrely provided with unambiguous evidence that the error in the pilot's control of the aircraft was directly attributable to an error in his perception of the motion and attitude of the aircraft. The conclusion that an accident was caused by spatial disorientation in flight must be obtained by inference which itself is likely to be influenced by the attitude, experience and judgement of the investigator (Benson,1978).

Accurate statistics are available only in the late 1960s.

R.G. Lofting reviewed the RAF Directorate Flght Safety records of investigation into flight accidents where disorientation was confirmed or probable cause in the decade 1960-1970 and pointed out that there is no special significance in the way the disorientation figures va throughout this period apart from the peaking of the incidents in the second quinquennium which is almost certainly due to a publicity campaign in the middle period which acknowledged the existence of the problem and encouraged the pilots to report their disorientation experiences.

B. Clark compared disorientation incidents reported by military pilots across 14 years of flight, that is, recent incidents reported by 336 US AF, Army and Navy pilots in 1970 with those reported by 137 in 1956 and found them strikingly similar for various types of aircraft and even for combat and non-combat situations and liable to be experienced in a wide variety of flight operations throughout the world and to continue to be experienced by military aircrfat pilots.

PE Tylor & PA Furr in their conclusions drawn from a survey of 2,000 naval aviators related to their experience with disorientation during various flight conditions stated that 96% of all aviators experience SDF at some time during their flying career, that the majority of accidents listing disorientation as a factor either are erroneously coded or the reports fail to provide sufficient evidence to validate the diagnosis of disorientation, the probability of the true incidence of disorientation caused incidents being very small (0.9%) for CY 1969.

WC Hixon, JT Niven & E Spezia began in 1970 a longitudinal series of reports dealing with the magnitude of the pilot disorientation/vertigo accident problem in Regular Army UH-1 helicopter operations.

According to Benson, in statistics extending over the 1970s for military and general avaition in the US and UK the orientation error accounts for 5 to 10% of all major accidents of both fixed and rotary wing aircraft. US general aviation statistics for the period 1964-1972 showed that 37% of major accidents involving light aircraft were attributable to SDF, in the UK 8.5% over the same period.

In its analysis of airtransport accidents, ICAO showed for the period 1959-1975 that 25% of the landing and approach accidents had a number of faftors conducive to spatial disorientation.

FR Tormes and FE Guedry performed a survey by means of a questionnaire concerning disorientation. It was answered by 104 active USN helicopter pilots anonymously and individually. 56% indicated one or more episodes of severe disorientation and 8.5% 5 or more times. 45% stated inability to read instruments due to vibration. 3 years later, in 1977 AP Steele-Perkins & DA Evans administered the same questionnaire adapted to the UK Royal Navy helicopter pilots and found respectively 52%,9%,35%. The most common phenomenon reported by the respondents was the "leans".

In 1977, WE Collins looked into the disorientation training in FAA-certificated flight and ground schools and found that more than one third of the respondents evaluated their disorientation training program as inadequate.

In 1978, WR Kirkham and associates reviewed the accidents reports made by the National Transportation Safety Board for a recent 6 year period. Statistical computations were made relating SDF to fatal accidents. SDF was involved in 2.5% of all general aviation accidents. However, SDF ranked as the third highest cause in fatal small fixed-wing aircraft accidents and is closely related to the second highest cause continued VFR flight into adverse weather. Inclement weather was associated with 42% of all fatal accidents, and SDF was a cause or a factor in 3.5% of these cases. Fog(56.8%) and rain (41.8%) were the most prevalent adverse weather conditions. Non-instrument related pilots were involved in 84.7% of SDF weather accidents. If SDF is associated with an accident, this is fatal 90% of the time.

Current aetiological factors & hazards to flight safety.

In this subsection a categorization borrowed from Benson (1978) shows the variety of casual factors of disorientation, broken down into two main headings, sensory input and mental processing, even if they are not mutually exclusive.

1) Sensory input

a) Visual cues - La désorientation spatiale apparaît lorsque le système visuel ne peut plus remplir son rôle (Colin,1978). Vision may be impaired by the reduction in retinal blood flow with G_z acceleration, the destabilization of retinal image (in FW aircraft when entering buffet boundary at high altitude or during turbulence at low altitude, in RW aircraft when applying maximum power as transition to hovering), blurring of vision due to VOR (during recovery from spin). Tracking performance was found to be impaired when the frequency of oscillation was increased beyond 0.8-1.0 Hz and attributable, in part, to involuntary eye movements consequent upon stimulation of the vestibulo-ovular reflex by the head turning movements (Barnes & Sommerville,1978).

External visual cues may be inadequate when the sight is degraded by sun glare, dazzle adverse meteorological conditions,featureless terrain, water lacking wave texture.

External visual cues may be erroneous. Pilots may feel that their aircraft is moving when they look at a wave pattern on water or long grass generated by the ground effect of the rotor. Comparable illusions of vertical motion are produced by the appearance and downward movement of water droplets or snow flakes entrained in the downwash of the rotor (Benson,1978). Flickering visual stimuli produced by the passing of shadow cast by the main rotor blades across the cockpit or by the light of a rotating anti-collison beacon may elicit a sensation of angular motion of the aircraft. Autokinesis (Aubert, 1887) which is probably due to changes in eye muscle tonus, typically occurs when a stationary observer looks at a small isolated and stationary target, such as a distant light, on a black night.The neural mechanism underlying smooth eye tracking may also be involved in the perception of continuous motion in the absence of real movement (Morgan,1978). That proprioceptive information about target location suppresses autokinesis was observed by Lackner,1977. Les petites accélérations angulaires et linéaires, même non percues, participent peut-être a la naissance de cette illusion (Chevaleraud,1978).

When the pilot becomes disorientated,he turns to the aircraft instruments. However, information provided by instruments may be erroneous because of breakdown or dynamic limitation.

In the approach and landing phase of flight the pilot is even more dependent on reliable visual cues and they are essentially monovisual cues since for distances greater than 10 meters stereopsis does not contribute to the perception of depth (Benson,1978). Relative motion parallax (a difference in rate of apparent movement of objects in the visual field), a cue that can contribute to visual judgments of glide path angle, was studied for its effect on the nighttime landing approach problem (Mertens,1978). A model was proposed to describe the pilot as a monitor of automatic landing system (Gai,1977).

b) Statokinetic cues - The vestibular organs (otoliths and canals) and their central perceptual mechanisms respond only to stimuli above the detection threshold and the dynamic range of the sensory system.

Inadequate cues probably account for the most important single causes of disorientation accidents. In fact,in accounts of disorientation incidents the absence of sensation is rarely reported; rather, it is the unexpected vertigo or other strong illusory sensation that is described (Benson,1978).

Erroneous cues are the cause of the most commonly described disorientation incidents in which the aviator is presented with a perceptual conflict.

Illusory perception of attitude

As Steele-Perkins' survey recently confirmed, a false sensation of bank, in aircrew jargon termed "the leans" is the most common illusion. The pilot is unaware of the low wing attitude or has the sensation of banking away from the level attitude. The illusion

stems from a sub-threshold roll or a recovery manoeuvre with change in angular velocity below 0.5-5°/sec. An additional cause is probably a minor directional asymmetry in the aviator's ability to detect changes in roll attitude. The conflict of sensory cues is easily resolved by reference to external visual and/or instrumental cues.

Somato-oculogravic illusions

The false perception of banking out of a flat turn ensues from the inability of the perceptual mechanism to distinguish the imposed acceleration from that of gravity. Conversely, a false sensation of level attitude will accompany the pilot during a coordinated turn because of the exposition to resultant vector of environment forces which, if sustained, is regarded as gravity and hence the vertical. These examples of somatogravic roll attitude illusions are less important from the viewpoint of flight safety than other somatogravic pitch-up attitude illusions or pitch-down attitude illusions sensed by the pilot during increase or decrease in linear acceleration of the aircraft during take-off, catapult launch, overshooting or, conversely, when applying air-brakes, because of backward c onward rotation of the resultant force vector. The visual component, namely the up/downward concomitant displacement of targets within the visual field is termed oculogravic illusion. Extreme cases are the jet upset and inversion illusions in case of weightlessness (Pichler,1973). Same illusions occur with an increase of unrotated gravity vector as during aircraft up/down-drafts. An experimental attempt to separate influences of otolith activity from neck proprioception was made by Cohen(1973). It has been recognized that the mechanism of the oculogravic illusion is not primarily related to eye movements. A dissociation in the perception of cues from the peripheral and vestibular mechanoreceptors has been suggested (Sparvieri,1974). Head movements performed during application of atypical environment forces elicit erroneous sensations of attitude changes containing elements of rotation attributable to the otolithic receptors in absence of cross-coupled stimulation of the semicircular canals.

Somato-oculogyral illusions

Erroneous sensation of turning or the absence of sensation during a coordinated turn, a sustained roll or spin are engendered by the semicircular canals responsive only to angular accelerations and unable to sense a steady rotational speed and therefore reacting only at the onset or the end of angular motion. The typical example of somatogyral illusion occurs at the time the pilot comes out of a spin when the semicircular canals are stimulated again and evoke a sensation of turning in the opposite direction. At this critical time vision may be degraded by nystagmus which is as inappropriate as the concomitant sensation of turning. The persistence of vertigo and the delayed suppression of eye movement can pose serious problems during spin recovery. The visual component occurring during spin recovery is cyclic in nature and accompanying the slow nystagmic phase; it is termed oculogyral illusion. The displacement of the light target after the initial blurring due to acuity decrement diminishes as the vertigo dies away, although the two illusions do not necessarily follow the same time course. Somato-oculogyral illusions on recovery from rotation around other body axes can be different in intensity because of less involvement of retinal image and interactions between otoliths and canals as well as anatomo-functional characteristics of the canals. Somatosensory motion after-effect following earth-horizontal rotation about the Z-axis was studied by Lackner&Graybiel (1977), and called a new illusion. Postural illusions experienced during Z-axis recumbent rotation and their dependence upon somat ensory stimulation on the body surface were described by Lackner & Graybiel(1978).

Coriolis illusion

Angular head movements in an abnormal force environment due to aircraft turning evoke cross-coupled responses of the semicircular canals. An analysis can be performed in terms of the Coriolis forces induced by the complex motion. The principal effect of a head movement in one axis during rotation about another orthogonal axis is to produce an illusory sensation of rotation in the third orthogonal axis. This applies to both somato- and concomitant oculo-gyral illusions provided the head movements are made during the sustained rotation and not at its start. Moreoever, otolithic responses are also involved in such situation which is classically depicted when during a descending instrument turn the pilot turns his head to operate side-located cockpit controls.

Cross-coupling effects were studied to distinguish disorienting and nauseogenic conditions. These proved able to be ameliorated by visual reference to the earth (Guedry,1978).

No correlation was found between motion sickness elicited by coriolis acceleration and capacity for spatial orientation (Vorobyev,1978). Active movement control is the most effective mode for adaptation to cross-coupled stimulation (Reason,1978).

False perceptions of attitude or motion are encountered together with blurring of vision in pathological conditions of Eustachian tubes probably because of asymmetrical pressure stimulation of the semicircular canals during changes in aircraft attitude (Benson,1978).

2) Mental processing

While error-prone because of its heuristic nature, the orientation perceptual process is also limited in its reliability by the physiological mechanisms and interactions of sensory organs in flight environment and, moreover, subject to influence by changes in other neurophysiological functions.

Erroneous perception of vertical motion as revealed by poor tracking performance was observed in absence of vision, thus suggesting a relative paucity of vestibular afferent information about vertical movement (Malcom,1973). Self-motion perception induced by convergence of visual inputs into the vestibular system is frequently experienced by observers viewing rotating scenes in their periphery (Dichgans,1978). Subjects often experienced illusory self-rotation when exposed to a rotating sound field. The appearance of nystagmus during illusory self-rotation indicates that apparent body orientation can influence oculomotor control (Lackner,1977).

Conflicting situations in which visual cues contradict vestibular and other proprioceptive cues result in disorientation incidents when the aviator is not able to disregard sensations of attitude or motion, particularly when the visual cues are reduced.

La désorientation est une situation dans laquelle le sujet ne fait plus la critique de ses semsations et tout se passe comme si le developpement de l'acte perceptif s'était arrêté au stade du percept primitif (Angiboust,1978). Perceived size and distance were analysed in terms of perceptual conflict between primary and secondary perception (Jigashiyama,1977).

Situations in which the awareness of environmental elements is restricted to a particular one may produce spatial disorientation.

This commonly occurs in the student pilot who, under the stress of attempting to perform a demanding and unfamiliar task, allows his attention to be confined to one aspect of his task. Yet even the experienced pilot, when presented with a high workload, when anxious, or when unduly aroused, can lose efficiency. (Benson,1978).

Sensory inputs may be misperceived because position and motion perception is based on past experience. Erroneous judgements of aircraft attitude, misinterpretation of lights when flying on a dark night, the so called "lean on the sun" are all examples of expectancy induced éerceptual error. The same applies to approach and landing situation, when visual cues are atypical and hence do not accord with expectancy (Benson,1978).

However, among the factors contributing to perceptual errors psychophysiological evidence supports the hypothesis of the predominance of unbalanced levels of neurophysiological arousal.

A moderate degree of emotional stress can improve efficiency of perceptive action and decrease the number of the subject's errors in the recognition of visual patterns (Simonov,1977).

A variety of false percepts of attitude and motion in flight environment appear to be primarily related to different levels of activation of the autonomic, peripheral and central nervous system. While drowsiness results in failure to perceive attitude and motion cues, a state of lowered cortical arousal arousal may account for that mental dissociation phenomenon termed "break-off from reality", no matter whether it is felt as an enjoyable experience or it may precipitate an anxiety reaction with consequent enhancement of cortical arousal and possible performance disruption.

Heightened neuropsychological arousal as in conditions of acute awareness elicited by imposed high workload or perceived threat, may result in behavioural regression with a return to more primitive or infantile modes of response, like the breakdown of complex learned flying skills and higher mental functions.

Heightened neurophysiological arousal of the autonomic and peripheral nervous system may account for disorientation phenomena as the "giant hand" because of postural hyper-reflectivity or reinstatement of vestibuloocular reflex activity by disruption of subcortical habituation.

Theories of spatial disorientation

There are really no theories encompassing all the factors of SDF. Attempts have been made to put forward conceptual mechanisms. However, these concepts are rather complementary and none could be given prominence over any of the others on the basis of experimental evidence.

In 1973, Benson proposed a conceptual scheme to show some of the vicious circle mechanisms by which spatial disorientation is potentiated. Afterwards he pointed out however that there is uncertainty about the end-organs stimulated and about the way in which afferent signals are processed and integrated with the CNS. Along the same line of reasoning in 1975, Reason &Graybiel presented a "neural mismatch" theory of motion sickness, and in 1978 von Baumgarten & Thumler developed a model of the mechanisms by which conflicting otolithic information is transmitted to higher brain centres.

Some theoretical statements based on neurophysiological models give an insight into mechanisms related with perception.

Neural filters drive the mechnisms of motion (Regan,1978). Feedback pathways preside over saccadic movements (Becker, 1979). Biofeedback ispredominant in perceptual experience (Correia,1977). Vestibular habituation is an active neural process (Collins,1974).

Some general psychological concepts, like expectancy or detection theories, can be invoked as factors influencing perception and explaining perceptual errors.

The findings available in literature lead one to conclude that the conceptual model able to predict and perhaps explain most of the disorientation phenomena is the arousal hypothesis. While there is ample evidence that arousal level is inadequate as a sole explanation, it appears to be an ubiquitous factor encountered in disorientation incidents.

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PERCENTUAL ERRORS IN FLIGHT - A SURVEW OF 100 MILITARY PILOTS ON ACTIVE DUTY

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SUMMARY

In the attempt to clear up some of the problems concerning perceptive disturbances in flight, we have subjected 80 military pilots and 20 cadet pilots in flight activity of different Air Bases to a survey consisting in answering an anonymous questionnaire.

We were able to confront the answers of the cadet pilots and the gradual disappearances of disturbances in them, in relation to an adjustment occuring with the number of flight hours. The data we have obtained confirm the importance that mental activities have in influencing perception and the role of the vestibule in causing disorientation.

INTRODUCTION

During flight, perceptive alterations are possible because to fly,is a condition abnormal to man, who is exposed to abnormal stimulus, which he must learn to dominate,in order not to run into disorientation, a frequent cause of flight accidents. We know that the sensorial data of perception, are conditioned by psychic elements such as motivation, attention, and particular states of mind. In certain situations, information coming from different organs in contrast with each other, may determine erroneous judgements,but can be caused also from a wrong central elaboration or from a particular psychological behaviour. With this aim, in order to try to clarify the neuro-psychological mechanisms that can be at the base of some perceptive disturbances, we have begun this study.

MATERIALS AND METHODS

We have examined 80 military pilots and 20 cadet pilots in a study that consists of answering a questionnaire. This questionnaire has been compiled using the collaboration of some military pilots, interviewed individually and in groups, who, informed of the aim, utility and limits of the research, have suggested the questions on the base of personal experience regarding perceptive disturbances during flight. All of the pilots interviewed in this phase, have been excluded from the study. The questionnaire has been preceded by an introduction about the theoric meaning of perceptive disturbances. The result is a single questionnaire of 116 questions, answered anonymously, made up of six parts:

- the first contains biographical data such as age, total hours of flight and the hours of flight activity during 1979, type of aircraft piloted, flight accident if any;

- the second part is relative to the possible correlation between on the one hand psycho-affective or psycho-social situation and type of mission and on the other hand disturbances if any;

- the third part refers to the correlation between on the one hand physical conditions, life, habits, the use of drugs and on the other hand possible perceptive alterations they can cause;

- the fourth part investigates the relations between the type of aircrafts and perceptive alterations;

- the fifth part deals with different atmospheric conditions in which the flight is possible; with some of the questions we investigate the duration of the disturbances and the time of the disappearance of these perceptive disturbances initially felt;

- the last part investigates the perceptive disturbances suffered out of the flight and the quality considered indispensable in avoiding them.

It has been asked moreover if the information about perceptive disturbances,which was given before the flight, was considered sufficient and if the pilots would find a theoric or practical knowledge of the problem more useful. The questionnaire was compiled so that for each single question it was possible to answer in three different ways YES NO I DONT'KNOW and in some cases to give a free response. The 100 military pilots, aged from 20 to 50, in flight activity, at different skill levels, from different bases, all in good health conditions, have been examined in this study. The pilots were so distributed:

a. 20 cadet pilots
b. 30 jet pilots
c. 30 engined aircraft pilots
d. 20 helicopter pilots.

In the evaluation of the results we have considered some data regarding all the subjects examined in this study and others concerning each single group.

RESULTS

The medium incidence of perceptive disturbances in the groups is 56% referred to the positive responses given, excluding doubts, with relative per-cent in the cadet pilots of 65%, in the jet pilots of 60%, in the engined aircraft pilots of 50%,and in the helicopter pilots we have found a percentage of 55%. There does not seem to be a relation with the total hours of flight, nor with the numbers of hours flown in 1979 (see table I). Among all the pilots interviewed in this study, only six have had flight accidents, four of them with jets and two with engined aircraft. The kind of alterations, most frequently found, are calculated as percentages of those who had suffered perceptive disturbances, they are:

1. Vestibular 70.44% with a relative percentage of 62.23% in group a., 85% in group b., 80% in group c., and 54.54% in group d.;

2. Visual 39.87% with a relative percentage of 7.69% in group a., 70.58% in b., 66.66% in c., 54.54% in d.;

3. Of other types 58.99 with a relative percentage of 30.76% in group a., of 75.58% in b., of 93.33% in c., of 36.36% in d.

With the same criteria we evaluated the duration of the perceptive disturbances and the time of their disappearance. The longest duration of the perceptive disturbances was less than 60 sec in 76.92% of group a., in 80% of group b., in 93.33% of group c., in 36.36% of group d., and between 60 sec and 4 minutes in 7.69% of a., in 15% of b., in 6.66% of c., and in 18.18% of d. (see table II). Some of the initial perceptive alterations gradualy disappeared in less than 25 hours from the beginning of flight activity in 69.23% of group a., in 45% of group b., in 20% of group c., in 36.36% of group d.; it took from 25 to 50 hours in 15.38% in a., in 5% in b., in 33.33% in c., and in 18.18% in d.; from 50 to 100 hours we had no response from group a. and d.,while we had in 10% of group b., and in 13.33% of group c. affirmative answers; from 100 to 200 hours we haven't had any response from group a. and b., with percentage of 3.38% in c. and 15.25% in d; the only answers we had for the disappearance of the disturbances for more than 200 hours come from group b. in 30% and from group c. in 33.33% (see table II).

In the evaluation of the remaining group of questions we considered the answers given not only those who had perceptive disturbances, but also by the total number of pilots. In fact some answers seemed to be given not only from direct experience but simply on the base of knowledge of such disturbances.

35% of group a. recognized a relation between psyco-affective elements and perce

ptive disturbances, 40% of group b, 44% of group c., while in group d. we have had an incidence of 30%.

45% of cadet pilots, 51% of jet pilots, 55% of engined pilots, 40% of helicopter pilots have had trouble in interpersonal relation within the working group.

It seems interesting to underline that 60% of group a., 63% of b., 75% of c.,and only 30% of d. indicate that economic worries facilitate these disturbances.

For 35% of group a., 30% of b., 50% of c., and none in group d., different aims of mission can cause disturbances. The group a. indicates with a percentage of 30% the different duration of the missions as a condition which facilitates the disturbances mentioned before, 17% of b., 40% of c., and 10% in d..

Night missions facilitate to a greater incidence of disturbances than day-time, with a percentage of 45% in group a. in which the doubtful answers have resulted in 40%, in 87% of group b., with 3% of doubtful answers, in 35% of c. with 5% of doubtful answers, while 70% of group d., in which no one gave doubtful answers.

All of the groups of study, except group d., indicate that to fly as a passenger instead of piloting, predisposes to the disturbances with the following percentage: 70% in group a., 56% in b., 45% in c., 20% in d..

The tension felt flying with a higher in rank affects the 20% of group a., the 30% of group b., the 40% of group c., the 30% of group d..

10% of group a. indicated that they had experienced fear in flying, 33% of group b., 15% of group c., and 40% of group d..

The disturbances of otorhinolaryngology and slightly unhealthy conditions facilitate possible erroneous perceptive judgments in 60% of group a., in 62% of group b., in 72.5% of c., and 40% of d.. According to 5% of group a., 7% of b., 20% of c., but none of group d., the use of drugs as ASA and antihistaminics may determine perceptive alteration.

7% of group a., 30% of b., 10% of c., 10% of d. had used alcohol before flying, although in habitual quantity, such as to cause perceptive disturbances.

We found quite interesting that 45% of group a., 50% of group b., 45% of group c., 40% of d. gave affirmative answer when asked if the increase of body weight influenced this kind of alteration. In particular alimentary excesses considered a condition that could influence perceptive disturbances in 70% of group a., 73% of b., 75% of c., 60% of d..

Flight in formation, at a low altitude, over inhabited places, on water or snow surface, may predispose to disturbances in an average of 35.75% and with relative percentage of 20% of group a., 53% of b., 40% of c., 30% of d..

Confidence in the instruments helps to avoid disorientation in 76% of group a., in 86% of b., in 85% of c., and in 60% of d.. All the groups of study judged the most useful instrument the artificial horizon with percentages of 60% in froup a., 87% in b., 70% in c., and 50% in d..

When the pilots were asked if their flight clothes were possible factors of perceptive disturbances, the answers were affirmative in 30% of group a., 33% in b., 40% in c., 40% in d., and particularly the helmet seemed to predispose to these disturbances in 15% of group a., in 14% of b., in 5% of c., in 20% of d..

Unfavorable atmospheric conditions (fog-clouds-turbolence) are factors influencing perceptive alterations in 25% of group a., in 44% of b., in 40% of c., in 40% of d.. In all the groups, flying with haze and clouds is the condition apt to determine most perceptive disturbances in 50% of group a., in 90% of b., in 85% of c., and 40% of d..

Out of flight 20% of group a., 23% of b., 25% of c., 20% of d. referred to have felt perceptive alterations.

85% of group a., 83% of b., 85% of c., and 80% of d. believed to have correct knowledge and consciousness of disturbances we are dealing about before answering the questionnaire.

The motivation and the efforts in flight activity may reduce perceptive disturbances in 50% of group a., 33% of group b., 53% of c., 10% of d.. The qualities considered apt to prevent possible perceptive disturbances have been prevalently calmness and attention in 46% of group a., confidence in the aircraft instruments in 20% of group b. and d., experience and skill in 35% of group c..

In the different groups comes out the existence of an individual tendency to suffer perceptive disturbances with the following percentage: 60% in group a., 46% in group b., 65% in group c., and 50% in group d..

The theoric information on this kind of disturbances was judged unsufficient before the flight in 90% of group a., in 66% of group b., in 60% of group c., and 70% of group d. (see table III).

The missing answers to the questionnaire have been 7.6% of group a., 4.8% of group b., 2.4% of group c., and 2.1% of group d..

CONCLUSION

From our resulting data the incidence of perceptive disturbances in flight is greater in cadet pilots, however in this group we have had the highest percentage of missing answers to the questions. This is probably due to two possible reasons, one that group a. is in an initial skill phase, with limitated flight experiences, and the other is that their is the tendency for unconscious mechanisms to hide certain responses. It is interesting to note that there does not seem to be a notable relation with the total flight hours probably because 26.25% of the pilots (that is more than half of those in which there has been a response) have had only 25 hours sufficient for the disappearance of initial disturbances. Other important data, concerns the duration of disturbances, that the largest part of the pilots indicate of 60 sec probably because there are elements of recuperation and compensation. In fact, from otoneurological studies, in the brain stem,control systems on the primary vestibular way have been discovered that correct abnormal input, favour the disappearance of the disturbances after few seconds. From these results it comes out that there are technical factors related to the aircraft and to the characteristics of the mission that can influence the development of perceptive disturbances and particularly psychological factors.

The psychological factors influence the perception and this modifies all the other psychological activities; this is a data that comes from literature and from different currents of study. The percentage of group a., referred to the psychological conditions that influence the disturbances in question, demonstrate in the cadets a lower incidence in respect to the other pilots. This result was unexpected and probably due to mechanisms of remotion or inhibition operating in this group. Fear seems to be in contrast with the hours of flight because the pilots, who have totalled a higher number of hours,have felt it more strongly. This is probably in relation to a greater sense of responsability of the experienced pilots, with regard of private problems concerning family and children or also to a major experience or consciousness of the problems and risks that the flight has. In all the groups of study we had a high percentage of perceptive disturbances related to economic worry perhaps because the pilots are conscious of their riskful and unsufficiently compensated activity. Among cadet pilots economic worries are less felt if confronted with the difficulty of the skill. Unexpectedly it must be mentioned in the cadet pilots the lowest percentage of incidences of perceptive disturbances while flying with a higher in rank, who may be an instructor, an authoritative figure, and this may suggest a possible tendency to infantile regression.

The qualities judged valid to prevent possible perceptive alterations have prevalently resulted in the calmness and concentration of the cadets, the confidence in the instruments in group b. and d., the experience and skills of the engined aircraft pilots. This unites ideal qualities of the military pilot and indicates in succession the indispensable characteristics in the formation of the pilot. The calmness and concentration result as the most important conditions for cadet pilots because the most difficult in order to aline the theoric notions with the difficulties of flight, considered as a new event, full of tension. The confidence in the instruments is according to us an expression of maturity and professionality of the pilot who becomes conscious of the objectivity of the instruments and the illusiveness of some of his perceptions. In all of the groups the existence of an individual predisposition to run into errors is affirmed,even if this is not scientifically demonstrated. All of the groups studied, with a prevalence in group a. of 90% affirmed that theoric information on perceptive disturbances is not sufficient. As far as the type of alteration, more frequently felt, is concerned,referred

to those who have mentioned perceptive disturbances (59/100 pilots), the higher medium incidence concerns vestibular disturbances with 9 cadet pilots over 13, 17/20 in group b., 12/15 in c., 6/11 in d.. This major influence of disturbances coming from vestibule in respect to other organs can be attributed to the fact that embriologically the ways of the vestibule are older in comparison with the visual systems. This may suggest that many perceptive disturbances derive from the conflict of contrasting information and when the vestibule is concerned. The importance this assumes, in phenomenon of vestibule adaption following the flight stimulus, is confirmed by some works in which it is affirmed the existence of a primary adaption that intervenes about 25 hours from the beginning of flight, as it is confirmed in our survey the high percentage of answers obtained in this regard.-

T A B L E I

Groups of Pilots	Incidence of perceptive disturbances		Flight Hours					
			In 1979			Total hours		
	Out of flight	In flight	Medium	Max	Min	Medium	Max	Min
a. Cadet Pilots	20%	65%	43.3	177	30	92	250	45
b. Jet Pilots	23.3%	60%	162.8	250	30	1,692	3,000	200
c. Engined Aircraft Pilots	26.6%	50%	195.2	370	14	2,831	6,800	120
d. Helicopter Pilots	20%	55%	190	300	70	1,740	4,350	150

T A B L E II

Groups of Pilots	Types of alterations more frequently felt, referred to those who had perceptive disturbances			Duration of perceptive disturbances		Time of disappearance of disturbances				
	Vestibular	Visual	Other Types	-60"	+1'-4'	-25h	25-50h	50-100h	100-200h	+200h
a.	62.23%	7.69%	30.76%	76.92%	7.69%	69.23%	15.38%	-	-	-
b.	85%	70.58%	75%	80%	15%	45%	5%	10%	-	30%
c c.	80%	66.66%	93.33%	93.33%	6.66%	20%	33.33%	13.33%	3.38%	33.33%
d.	54.54%	54.54%	36.36%	72.72%	18.18%	36.36%	18.18%	-	15.25%	-
Medium Incidence	70.44%	49.87%	58.99%	80.74%	11.88%	42.65%	17.97%	5.83%	4.66%	15.83%

TABLE III

	Groups of Pilots				
	a	b	c	d	Medium
1. Psyco-affective conditions	35%	40%	44%	30%	27.25%
2. Interpersonal relations	45%	51%	55%	40%	47.75%
3. Economic worries	60%	63%	75%	30%	57%
4. Aim of mission	35%	30%	50%	-	28.75%
5. Different duration of mission	30%	17%	40%	10%	24.25%
6. Night mission	45%	87%	85%	70%	71.75%
7. Higher in rank on the aircraft	20%	30%	40%	30%	30%
8. Fear of flying	10%	33%	15%	40%	24.50%
9. Diseases	60%	62%	72.5%	40%	58.60%
10. Drugs	5%	7%	20%	-	8%
11. Alcohol	7%	30%	10%	10%	14.25%
12. Weight	45%	50%	45%	40%	45%
13. Alimentary excesses	70%	73%	75%	60%	69.50%
14. Type of flight	20%	53%	40%	30%	35.75%
15. Confidence in the instruments	76%	86%	85%	60%	76.75%
16. Flight clothes	30%	33%	40%	40%	35.75%
17. Helmet	15%	14%	5%	20%	13.50%
18. Atmospheric conditions	25%	44%	40%	40%	37.25%
19. Clouds - haze	50%	90%	85%	40%	66.25%
20. Knowledge and consciousness of perceptive disturbances	85%	83%	85%	80%	83.25%

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THE AMBIENT VISUAL SYSTEM AND SPATIAL ORIENTATION

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SUMMARY

The recently developed concept of two modes of processing visual information is reviewed with particular emphasis on their independent functions and the role of the ambient visual system in orientation. The multisensory basis of orientation and the central integration of signals are discussed. Disorientation is assumed to result from a mismatch, in comparison with the previous experience of the individual, of these simultaneously occurring signal patterns. It is suggested that disorientation in aircraft under instrument flight conditions may result from the substitution of an "unnatural" symbolic indicator to replace the visual stimuli normally involved in orientation and the failure of a learned cognitive skill to compensate for mismatched signals.

Recently, a new concept has been introduced regarding visually controlled behavior which may have implications for the problem of disorientation in aircraft. The formulation of "two-visual systems" suggests that there are independent means of processing visual stimuli which have different psychophysical and neurological characteristics and which subserve different aspects of visually controlled behavior.[1] This distinction was first suggested by ablation studies and the small but growing literature frequently makes reference to anatomical structures. However, because the neuroanatomical considerations are complex in humans, and at this point there are so many unanswered questions about them, they will not be treated in the present context. Rather, we propose to follow Held's suggestion to emphasize the functional differences between "two modes of processing spatially distributed information" and their implications.[2]

These are:

(1) A *focal mode* which is concerned with object recognition and identification and in general answers the question of "what". Focal vision involves relatively fine detail (high spatial frequencies) and is correspondingly best represented in the central visual fields. Information processed by focal vision is ordinarily well represented in consciousness and is critically related to physical parameters such as stimulus energy and refractive error. The vast majority of studies in "vision" as well as most existing tests for evaluating performance or individual differences are concerned with focal functions.

(2) *An ambient mode* which subserves spatial localization and orientation and is in general concerned with the question of "where". Ambient vision is mediated by relatively large stimulus patterns so that it typically involves stimulation of the peripheral visual field and relatively coarse detail (low spatial frequencies). Unlike focal vision, ambient vision is not systematically related to either stimulus energy or optical image quality. Rather, provided the stimulus is visible, orientation responses appear to be elicited on an "all or none" basis. Presumably because they involve subcortical structures, the conscious concomitant of ambient stimulation is low or frequently completely absent. Interest in ambient visual function has a long history, but analysis of psychophysical properties, evaluation of developmental aspects, interaction with other sensory systems, and implications for human engineering have been initiated primarily within the past ten to fifteen years.

An important aspect of these two modes of processing is that they can be dissociated. Such dissociation can easily be demonstrated by considering the fact that one can walk while reading. Although attention is concentrated in the central visual field, maintenance of body posture, locomotion, and avoidance of most obstacles is readily accomplished efficiently and confidently by peripheral vision with little or no conscious awareness. A number of studies have

demonstrated dissociation in brain damage subjects for whom object recognition is impaired or lost but orientation responses remain[3-6]. Weiskrantz[4] and his colleagues have labeled this phenomenon "blindsight" and it is generally assumed to be subserved by subcortical structures which have survived insult to the cortex.

Striking differences between focal and ambient vision can also be demonstrated in normal observers by systematic manipulation of physical parameters. It is well known that focal functions such as resolution of fine detail are critically dependent on both stimulus energy and the optical quality of the retinal image. Although the functional luminance range of the visual system extends over at least ten log units, reduction of illuminance below about ten foot candles will impair resolution capacity even though this level is still nine log units above absolute threshold. Similarly, a refractive error of 0.25 or 0.5 diopter will significantly degrade acuity and an uncorrectable error of 2.5 to 3.0 diopters will result in legal blindness in the United States. However, vection, the illusory sensation of self-motion elicited by the movement of large portions of the visual field produces the same response parameters over the entire functional range of illuminance even when viewing through 20 diopter positive lenses[7].

Evidence has been gradually accumulating to suggest that as a general rule orientation responses are independent of the variables of luminance and optical quality which play such a critical role in focal vision as long as stimulation remains above threshold. To date, data supporting this position have been obtained for linear[8], circular[7] and roll vection, radial localization of stimuli[9-10], and nystagmus[11].

The distinction between focal and ambient vision is useful for a number of reasons. It is helpful in organizing our knowledge of visually controlled behavior, is important in understanding the effects of brain damage, provides guidelines for development of tests for evaluation of performance in the clinic as well as in human engineering, suggests explanation for previously unexplained phenomena in the human performance literature, and is critical in the development of our understanding of the relationships among vision and other sensory systems.

As an example of a puzzling phenomenon which may be better understood in terms of the two systems concept, consider the fact that a disproportionate number of traffic accidents occurs at night. Although many factors contribute to nighttime traffic accidents, reports of a reduction in the accident rate when illumination is introduced argue for the importance of vision. Analysis of driving in terms of the two modes of processing concept assumes that steering of the automobile is an ambient function which is subserved primarily by stimuli impinging on the peripheral visual field[12]. On the other hand, recognition of obstacles such as pedestrians, animals, potholes, etc. is a focal function involving the central visual field. During daylight, both modes of processing function normally and at their maximum capacities. However, with reduced illumination, the efficiency of the focal mode is sharply reduced both as a result of lowered illumination and, in many cases, night myopia[13]. The net result is that unexpected hazards on the motorway not only are recognized later than during daylight, but avoidance responses are slowed by the increase in reaction time associated with lower illumination[14]. However, under the same conditions the ambient mode is operating at the same efficiency level as during daylight. There is no reduction in the ability to steer the vehicle so that vehicle speeds at night are the same if not somewhat faster than during daylight. In effect, drivers behave as if they are not aware of the selective degradation of focal vision.

The net result of this over-confidence based on the immunity of ambient vision to lowered illumination and the consequences of degraded focal vision is highway speeds which are too fast to permit adequate response to hazards on the roadway. Additional factors which accentuate this tendency are the low level of awareness of ambient mediated functions and the relative infrequency of highway hazards.

Consideration of ambient vision is necessary in order to understand the mechanisms underlying the maintenance of body posture, orientation, and locomotion[15]. These functions depend on multiple sensory systems, primarily vestibular, (ambient) vision and somatosensory inputs. Explanation of vection[15], disorientation, and height vertigo[16] have emphasized the interaction among these subsystems in spatial orientation and the appearance of disorientation and motion sickness when a mismatch occurs[16,17,18]. Specifically, normal activity simultaneously activates the several sensory systems mediating orientation which are integrated centrally. However, any deviation from this familiar pattern results in a "mismatch" and disorientation. A severe mismatch produces nausea which serves as a warning that the organism should attempt to eliminate the environmental conditons under which accurate orientation is not possible. The data on vection, height vertigo, motion sickness, and adaptation to unusual body motion are amenable to an explanation based on this model.

An example of the effects of a systematic mismatch between visual and vestibular signals has been demonstrated by Dichgans and Brandt[15]. While subjects were rotated at a constant velocity, they made controlled head movements to produce Coriolis stimulation and feelings of vertigo. At the same time, a striped drum surrounding the subjects was rotated either in the same direction as subject rotation, or in the opposite direction. When the motion of the drum was such that the visual environment moved opposite to subject motion so that there was concordant visual and vestibular information concerning self-motion, there was some report of vertigo. However, when the drum rotated in the *same* direction as the subjects, the resulting mismatch of visual and vestibular information concerning self-motion resulted in significantly increased vertigo. Under this latter condition, the greater the speed of the drum, the greater the mismatch, and the more intense the feeling of vertigo.

A similar analysis has been offered by Brandt to explain motion sickness in automobiles[17]. Motion of the vehicle activates the vestibular and somatosensory systems while visual stimulation is simultaneously provided by both the interior of the vehicle and the landscape visible through the car windows. For the driver, the visual cues available from the landscape move in the appropriate direction, i.e., opposite to the vehicle motion, and stimulate large portions of the visual fields. The result is that drivers and front seat passengers rarely become motion sick. However, for a passenger in the rear seat of the vehicle, a significantly larger portion of the visual field is stimulated by the moving interior of the vehicle and less by the stable outside environment. Accordingly, more discomfort is reported by rear seat passengers than by those in the front. That reduction in the ratio of the stable outside scene to total visual stimulation is responsible as suggested by the familiar observation that reading in an automobile or any other behavior which reduces visual stimulation by the stable environment results in a corresponding increase in discomfort.

The same reasoning may apply to aircraft disorientation under instrument flight conditions. In this case, every motion of the aircraft produces a mismatch of visual and vestibular information. By training and with the aid of instruments, disorientation and motion sickness are for the most part avoided. There are however frequent reports of disorientation even among experienced pilots and such disorientation has been implicated in accidents[18]. We should like to speculate that some of these reports of disorientation can be interpreted in terms of the concept of the *two modes of processing visual information*. Specifically, under normal conditions, the visual stimuli involved in orientation are mediated by stimulation of large portions of the visual fields, primarily in the periphery. During self-movement, motion of the visual environment agrees with signals from the vestibular system in accordance with past experience. However, in the aircraft under instrument flight, the only reliable visual source of orientation is presented to a small (typically 5 degrees) portion of the central visual field. At the same time, large portions of the visual field are receiving signals which are not in agreement with normal experience. There is no question that human beings are extremely adaptable and are capable of adjusting to new patterns of relationships to environmental stimuli. Thus, the substitution of a small symbolic display can and in most cases does serve as an adequate source of orientation information under instrument conditions. However, in relation to the normal role of vision in orientation, a small symbolic display is essentially an "unnatural" stimulus which must be processed by mechanisms which are not normally concerned with orientation information. It is well known that under atypical stimulation, unusual environmental conditions, or stress, the first abilities to be impaired are learned cognitive functions, specifically those which have been more recently acquired in the history of the organism. It may be that disorientation in aircraft results from a failure to orient by means of a small symbolic indicator with a subdivision of the visual system which is ordinarily not involved in orientation. The fact that disorientation is initiated by atypical patterns of stimulation, may persist for long periods of time, and is rarely observed when "normal" (large stable) orientation stimuli are visible is consistent with this hypothesis.

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VISUAL ILLUSIONS AS A PROBABLE CAUSE OF AIRCRAFT ACCIDENTS

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SUMMARY

A visual illusion is the perception of something objectively existing but in such a manner as to cause misinterpretation of its actual nature. Spatial disorientation, visual restrictions, and illusions are important factors in the causation of aircraft accidents. This has been documented by the studies of Bell and Chunn (1) and Nutall and Sanford (2). Visual illusions can cause errors in judgment that at times cannot be compensated for by corrective actions or maneuvers. For example, the reduced visual cues received by the pilot during night and inclement weather landings complicate the distance judgment problem. Runway widths, slopes and terrain features all play important parts in depth judgment estimates made by the pilot. The most critical time for the pilot is when he comes off his instruments and goes visual. This paper will analyze a number of United States Air Force aircraft accidents in which visual illusions appear to be a significant or contributing factor in the accident. Such factors as rain on the windshield, flashblindness by high intensity strobe lights, disorientation by flickering lights and ground light intensity variations appear to have led to errors in judgment, thus directly contributing to the aircraft accident. A studied awareness of these factors is the pilot's best corrective action available.

I. INTRODUCTION

A visual illusion is the perception of something objectively existing but in such a manner as to cause misinterpretation of its actual nature. Spatial disorientation, visual restrictions, and illusions are important factors in the causation of aircraft accidents. In their study, Bell and Chunn (1) showed that spatial disorientation and vision restrictions were the psychophysiologic factors responsible for approximately 23% of the aircraft accidents they investigated. Visual illusions can cause errors in judgment that at times cannot be compensated for by corrective actions or maneuvers; for example, the reduced visual cues received by the pilot during night and inclement weather landings complicate the distance judgment problems, thus not allowing him enough time to take corrective action. Another critical time for the pilot is when he comes off his instruments and goes visual. It is at these moments that illusions play a significant part in the causation of aircraft accidents and incidents. We will now briefly review the visual factors which contribute to disorientation or faulty distance judgment and then analyze a number of aircraft incidents and accidents in which visual factors appear to play a significant role.

II. BACKGROUND

In his article entitled "Visual Illusions," Richard Gregory (3) asked: "Why do simple figures sometimes appear distorted or ambiguous? Perhaps because the visual system has to make sense of the world in which everyday objects are normally distorted by perspective." We are aware that illusions can occur in any of our senses and they can cross over between them. Small objects feel heavier to us than larger objects weighing the same. Apparently, we perceive weight not only by our kinesthetic and pressure senses but also to what we expect the object to weigh as interpreted by our visual sense.

There obviously is a large element of learning in our perception of the real world, but for the aviator another one of these learned phenomena that is important is the apparent unchanged size of the perceived image of an object as its distance from the observer changes. The retinal image reduces in size as the observer moves away from the object; the mental image, however, does not change proportionally. This is the perceptual phenomena of size constancy. The depth dimension of visual space is another important element for the flier. It is through retinal disparity or the displacement of images on the two retinas that the aviator can view the world stereoscopically or in three dimensions. Some of the visual factors contributing to disorientation will now be looked at.

Aircraft windshields may cause refraction, magnification, and distortion of images. Windshields with good optical surfaces, such as those made of glass, should not impair the pilot's size, distance, and depth judgment. Newer windscreens of laminated plastic are being studied to see if their higher amounts of distortion and multiple image formation are truly a real hazard. To date, however, we have not been aware of any accident that could be directly attributed to these factors. We do have strong evidence that improper or uncorrected refractive errors and the improper use of spectacles may have been contributory to several accidents.

Heavy rain can change the optical characteristics of aircraft windscreens. Stedman (4) has reported that rain could reduce vision enough to render invisible such objects as aircraft, power lines, flag poles, and trees. Also, if rain is not removed from the windscreen, ripples, blurs and droplets can act as prisms and may deceive the pilot into his not being able to orient himself properly in relationship to the ground. Further, rain may cause faulty distance judgment since by acting as a filter, lights may appear less intense and therefore give one the illusion of being at a greater distance.

Visual input into the decision-making process of the pilot is most critical during the landing phase. It is here that the pilot is also the busiest--his visual attention must be shared with multiple other procedures necessary for carrying out a safe and smooth landing. It is at this point in flight that depth perception or, better termed, spatial localization is an absolute necessity for the pilot. Depth perception is the mental projection onto visual space of a perceived object in real space.

Correlation of a real object in real space with a projected object in visual space results in accurate depth perception.

There are both monocular and binocular cues to this perception of depth (5). The monocular cues are: 1) size of the retinal image (size constancy)--being able to judge the known and comparative size of objects is a most important clue; 2) motion parallax--the relative speed of motion of images across the retina; objects nearer than fixation point move against the observer's motion, more distant objects move in the same direction as the observer's motion; 3) interposition--one object obscured from vision by another; 4) texture or gradient--detail loss at increasing distances; 5) linear perspective--parallel lines converging at distance; 6) apparent foreshortening--a circle appears as an ellipsis at an angle, etc.; 7) illumination perspective--light sources are usually assumed as coming from above; and 8) aerial perspective--distant objects appear more bluish and hazy.

The binocular cues to depth perception are convergence and accommodation, useful only for very near distances and stereopsis--this being the visual appreciation of three dimensions during binocular vision. It occurs due to the fusion of signals from slightly disparate retinal points, disparate enough to stimulate stereopsis but not so disparate so as to cause diplopia.

Of the monocular cues, the two most important factors for flying are motion parallax and size of the retinal image, according to Ogle (6). Monocular cues are derived from experience and subject to interpretation. It is here that illusions play their strongest role. Stereopsis, on the other hand, is based on a physiologic process and is innate and inescapable so that at times when vision is degraded and the monocular cues are sparse or nonexistent, one must eventually fall back onto the individual's capability of judging depth by stereopsis alone.

The elements of flying in which illusions play a most important role are the approach and runway problems. It is here--the most critical phase of the flight--where the pilot comes off of his instruments and onto the use of his own vision that reduced or illusionary visual cues complicate his distance judgment; and now being close to the ground, he has very little time to reconsider or reevaluate the visual input. A judgment, of necessity, must be forthcoming, and at times an incorrect decision is made resulting in an accident.

Visual illusions and misinterpretations on landing can be caused by runway and approach lights--also by the effect of haze or fog on his distance judgment while viewing the runway lights. Even during times of unrestricted vision, either day or night, according to Pitts (7), landing judgment may be faulty because of illusions caused by size of the runway, especially its width, if it differs markedly from the runways that the pilot is usually accustomed to. Improper approaches are often made because of improper estimation of height above the ground due to sloping approach terrain or sloping runway. The pilot will have a tendency to land short on an upsloping runway or where the terrain in front of the runway downslopes. He will have a tendency to overshoot when the runway is downsloping or if the terrain in front of the runway is upsloping.

Another hazardous aspect of landing is over water, desert, or snow where visual cues are at an absolute minimum. Pilots not accustomed to landing on water or in a desert or arctic region will tend to undershot the runway. And, finally, external objects on the approach patch may serve as false cues to height. As an example, if a pilot were accustomed to landing with an approach over large, evergreen or spruce trees and were then required to land in the Aleutians, he might misjudge his height and distance from the runway because the spruce trees in the Aleutians are quite small and scrubby. Thus in attempting to create his visual perception of tall evergreens he would have to descend to a lower altitude.

III. INCIDENTS AND ACCIDENTS

The Ophthalmology Branch at the USAF School of Aerospace Medicine is often called upon in consultation to determine if visual factors have played a role in USAF aircraft accidents or incidents. Following we will evaluate a number of USAF and civilian flying incidents and accidents in which we were asked our opinion as to the role visual factors may have played.

CASE #1. A civilian pilot with a fair amount of experience in landing light aircraft on water misjudged his landing onto the water, struck his pontoons and the aircraft sustained major damage. There was apparently no restriction in visibility; it was a familiar landing area, etc. The only point of difference from the usual was that the aviator had just acquired a new pair of spectacles which were, in essence, his first bifocals. It is possible that an aviator may need a special pair of spectacles to be used just for flying--for instance, if the bifocal segment is set a bit high or the patient is not experienced in lowering his head so as to continuously look through the upper distance segment during the landing, he may get an extremely distorted view of the runway or water if he is viewing through the lower (bifocal) or even through the intermediate (trifocal) segment. Anyone wearing a pair of bifocals can experience that phenomenon for himself by simply tilting his head backwards and attempting to view a distant scene through the bifocal. The distortion is of such a magnitude as to definitely impair one's landing capabilities.

CASE #2. A jet aircraft with both pilot and copilot on board made a near perfect night landing; however, the landing was in the water several hundred yards short of a coastal runway. In this case, it appeared that the weather was probably a contributing factor since the visibility was down to very close to the one-mile minimum and other pilots had been diverted from this airfield earlier that evening. However, another contributing factor might have been that the pilot was not wearing his glasses at the time of the accident.

Most Air Force pilots are emmetropic or if they have a refractive error are hypermetropic; therefore, they maintain excellent distant vision throughout their flying careers. However, being human, they too become presbyopic. Early in the condition the aviator hardly notices his deficiency

for near vision except under the most stressful conditions, such as attempting to read small numerals under poor illumination or under red illumination. Therefore, early presbyopes not wearing their correction could misread any of the number of dials that an aviator must scan throughout the flying mission, such as misreading the altimeter or airspeed, both critical during the landing phase. Again, if one is a presbyope he can demonstrate this to himself quite dramatically, such as when driving his car at night. One can easily view the road and outside surroundings through his upper segment or without a lens; however, if this presbyopic driver attempts to read his speedometer or odometer while looking at it through his distance segment or without bifocal correction, he will get only a rough approximation of the speed and will not be able to read his odometer nor almost any other numerals on the panel.

CASE #3. This is the final one that deals with distortions in vision--in other words, erroneous sensory input from which correct judgments will obviously be largely a matter of chance. In this accident two Air Force aircraft collided in midair--one of the two aircraft lost its canopy. At that point the pilot of this aircraft was flying with his visor up and because of the loss of the canopy the windblast onto his face was of such extreme magnitude that he lost all ability to maintain visual control of the aircraft. The pilot therefore ejected. The aircraft was lost. Questioning several pilots, we became aware that many pilots do not wear their visor in the down position because they feel that there is a loss of visual acuity through the visor. This perhaps is a feeling or illusion that the aviator may have since he must now look through one more transparency. It is possible that occasionally one of the visors of poor quality passes inspection and is an actual impairment.

Ophthalmology Branch personnel did perform a study recently comparing certain visors but no loss of acuity was found in this study. The visor is an additional protective element; however, if a pilot feels that it is a visual impediment, he will not wear it in the down position.

The next several cases deal with the problem of flicker and flashblindness and their possible effects on aircraft accidents.

CASE #4. This case concerns a USAF pilot who was making a landing approach in poor weather; i.e., there were low clouds and haze through which he was penetrating. He apparently became mesmerized by the aircraft's strobe lights pulsating and being reflected back from the surrounding clouds. With some difficulty he did land the aircraft so that this should be classified as an incident rather than an an accident.

Back during the 1940's it was discovered that the alpha wave of the electroencephalogram could be controlled by photic driving. Later it was discovered that at certain frequencies seizures could be induced in some small number of epileptics. In each case the frequency range that was defective in the photic driving was found to be 10 to 15 flashes per second thus the flickering of light through a helicopter rotor blade or pulsating strobe lights could possibly be a stimulus to induce detrimental effects. Johnson (8) reported that approximately 25% of helicopter pilots experience annoying, distracting or irritating sensations at times due to the flicker effect of their rotating blades. Christner (9) reviewed the literature on the effects of flicker and concluded that there are two basic effects--one is the photically induced epileptic seizure which however occurs only in a small proportion of even the epileptic population. The second effect ranges from annoyance through distraction to dizziness and headache. This is probably the most important aspect for the aviation population since there is the possibility of degradation of performance which might be the result of the "distraction" of flicker.

At times high intensity strobes or other bright lights on the approach may flashblind the pilot so that temporarily his vision will be degraded. This should not last any longer than seconds; however, even seconds are at times important in a critical situation.

CASE #5. Two aircraft were making a formation landing at night in a light fog. They missed the first approach and on the second approach the wingman contacted the ground approximately 1500 ft. short of the runway. He became airborne again 400 ft. short of the overrun. Miraculously, the pilots of the wing aircraft ejected at an altitude of approximately 60 ft., both making a safe parachute landing. The aircraft crashed and burned.

The visual aspects of the accident were as follows: On the go-around the lead ship asked that the strobe lights be turned up to full intensity. On the second approach the strobe lights appeared much brighter than usual to the crew in the wing aircraft and because of the fog little could be seen other than the lead plane. It appears that the wingman suffered some visual confusion due to the brightness and stroboscopic effect of the lights. The pilot reported that he could see the lead plane clearly in the flashes as the strobe lights went off and on, which produced a jerky movement effect due to the apparent stop action. This obviously increased the difficulty of formation flying. The intensity and the stroboscopic effect of the lights in the fog were felt to be contributing factors since the haze generated in this fashion obscured other visual cues necessary for orientation. The pilot was unaware that he had made ground contact.

CASE #6. This aircraft accident occurred under nighttime conditions in blowing snow. Further, it was felt that the pilot was not wearing corrective spectacles so this would have deprived him of his stereopsis. A study of the visual factors in this case showed that the pilot needed all the depth cues that he could possibly extract from the visual scene and in this case stereopsis might have been the only reliable cue available; however, without his spectacles it was felt that his stereoscopic input was degraded.

The monocular visual cues that are usually used gaining depth perception were only minimally available to this pilot since it was dark, was blowing snow, the contours and outlines were poor, and the differences between light and dark were not well distinguished. The flight surgeon further reported that the center line at the airstrip was not visible. Further, this pilot was looking into the high intensity strobe lights on his approach, which could further have degraded both his dark adaptation and his central vision. It was felt that a combination of these factors was additive and played a part in the aircraft accident.

The last three cases deal with the illusion of height over featureless terrains. It is well known to the aviator that visual descent over calm sea, desert, or snow or even over unlit terrain at night can be hazardous even with good visibility. Without external vertical references, it is quite difficult to judge one's height over the terrain, and often the pilot has the illusion of being at a greater height than he actually is thus leading to a too rapid descent and contact with the terrain before he had anticipated it.

CASE #7. Two crashes involving USAF aircraft might have fallen into this category. Both were flying over featureless desert terrain; one impacted into the target; a second aircraft on a similar mission flew into the ground at a low angle of attack. Both of these flights were low altitude missions over desert terrain. No known malfunction of the aircraft had occurred; therefore, the possibility of erroneous depth judgment has to be considered. A somewhat similar case is one reported of a recent commercial aircraft in which 257 lives were lost while flying on a sight-seeing mission over the Antarctic. The exact cause of the crash is still undetermined; however, there was no evidence that the aircraft was defective. It was, however, reported that the veteran pilot was making his first flight on this particular polar route. Even though speculative, one nevertheless must consider that the pilot may have become a victim of a whiteout, in which orientation becomes quite difficult since this has often been described by pilots, who have been trapped in similar situations, as "flying in a bowl of milk."

IV. DISCUSSION

Aircraft accidents that may have been caused by visual illusions, disorientation and visual restrictions are most often quite difficult to evaluate. These parameters do not really lend themselves to quantitative analysis; it is not the same as measuring blood alcohol or blood gases of the pilot or searching the wreckage for a defective part. The increasing aircraft speeds and complexity of the mission have further complicated things. There is less time to make re-evaluations of a situation. Decisions must be made in shorter time spans, leaving even less time for corrective action if the first decision was felt to be erroneous. We have not discussed illusions produced by angular and linear acceleration; however, these are the ones that all capable instrument pilots can overcome by simply flying on instruments. Visual illusions, on the other hand, become manifest mainly when the pilot comes off his instruments and relies on his visual apparatus. A pilot should, therefore, always cross-check his visual attitude with his instrument attitude and believe his instruments. Pilots are trained to rely on their instruments although the information may be opposite of the seat-of-their-pants' orientation cues. Sometimes during stressful situations this is forgotten, and the pilot erroneously goes back to his basic physiologic sensors, with at times disastrous results.

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DISCUSSION

- M.F. HAWKINS (U.K.)

In aircraft in which digital instrumentation is used,we can insist on the presentation to be green and not red as presbytes cannot read red figures.

. Author's reply :

I am in agreement with Dr HAWKINS that green or blue-green targets are much easier to see for presbyopes or hypermetropes.

Red was originally selected during World War II to preserve night vision.

Probably a good compromise is to use low intensity white illumination as it is often done in present day aircraft.

- ALNAES (Norway)

Comment on digital instrumentation for the presbyopic aviator.

. Author's reply :

Digital readouts give more information.However I don't believe that one can scan and retrieve information as quickly as the aviator obtains them from analogic instruments (dials) .

The intensity of illumination of present day digitals is also weaker than on the dials .

This could be a problem in certain lighting condition.The color of the digits (and the background) is also important since they are factors in contrast.

Red digital displays are a poor choice (color) because of the additive effect of chromatic aberration of the eye on presbyopic and hypermetropic individuals .

DISORIENTATION IN ARMY HELICOPTER OPERATIONS

A General Review

by

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and
Maj. C.J. Box, RAMC

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INTRODUCTION

1. Since 1963 the Army Air Corps (AAC) has had 185 helicopter accidents, resulting in 53 fatalities (as at 1 Mar 80). A detailed search of the records held at the Headquarters Director Army Air Corps has révealed 40 accidents in which a serviceable aircraft was flown into the ground or sea.

2. Accidents involving aircraft mishandled during take off, landing or tactical low flying (or nap of the earth (NOE) flight) account for 12 of the 40 accidents. 28 accidents occurred, with the loss of 18 lives, in which inadvertent height loss or insufficient terrain or obstacle clearance occurred, resulting in ground impact. These 28 accidents have been classified as orientation error.

3. This review considers orientation error accident rates, the types of accident, influencing factors, and the in flight disorientation training sortie being developed for use on the Army Pilots Course.

ORIENTATION ERROR ACCIDENTS

4. It is not possible to categorically state the exact sequence of events immediately prior to ground impact in most fatal accidents. Accident investigation will provide detailed information, but in some instances the orientation error label can only be applied circumstantially after the exclusion of technical or medical causes. For operational or other reasons, not all accidents were subject to detailed investigation. Consequently the accidents that could not be reliably included as orientation error have not been considered.

5. The AAC flies on average 1000,000 helicopter hours per year, and as rates per 10,000 hours per year, the orientation error accident rates and orientation error fatality rate are shown in Figs 1 and 2.

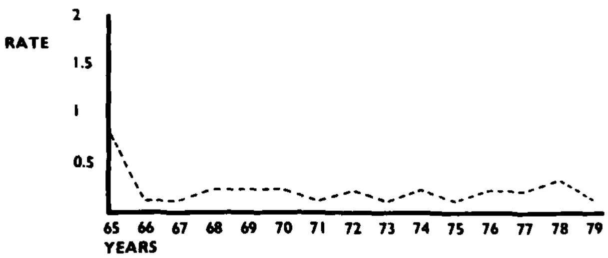


Fig 1. Helicopter orientation error accident rate

Fig 2. Helicopter orientation error accident fatality rates

6. The annual figures are too small to draw significant conclusions, but if the total figures are considered during the period more useful interpretation is possible. (Table 1).

TABLE 1

HELICOPTER ACCIDENTS 1963-80 TOTAL ACCIDENTS AND GROUND IMPACT WITH SERVICEABLE AIRCRAFT ACCIDENTS

HELICOPTER ACCIDENTS 1963-80
TOTAL ACCIDENTS AND GROUND IMPACT
WITH SERVICEABLE AIRCRAFT ACCIDENTS

	TOTAL	SERVICEABLE AIRCRAFT	
		NOE GROUP	ORIENTATION ERROR
ACCIDENTS	185	12 (6.5%)	28 (15.1%)
FATALITIES	53	0 (0)	18 (34.0%)

7. Light helicopter accidents produce a random range of injury, varying from such extremes as no injury in a total disintegration of the aircraft, to fatal injuries in a minor impact due to fire or main rotor blade/body contact. Patterns of injury are difficult to elicit and so have not been included in this review.

8. Table 1 shows that the serviceable aircraft accident group accounts for 21.6% of all accidents, and 34.0% of all fatalities. However the fatalities all occur in the orientation error group (15.1% of all accidents). This can be explained as follows:

a. NOE Group (6.5% of all accidents - no fatalities). The take-off and landing accidents occur at lower airspeeds and the crew are at a high vigilance level. The noe flight accidents mainly occur at speeds below normal cruise and again the crew have a high vigilance level. Reaction to the error made and appropriate actions prior to impact reduce the speed and impact forces.

b. Orientation Error Group (15.1% of all accidents, 34% of all fatalities). The different types of accident are described later, but for a significant number the error is one of mis-orientation and unexpected ground impact at cruise speed (100 kts+), or one of spatial disorientation at altitude and an uncontrolled descent to impact. In both circumstances the speeds and forces are often beyond the limits of seat, harness, helmet, and aircraft performance and of body survivability.

ORIENTATION ERROR ACCIDENTS

9. Helicopter crews are as susceptible to disorientation as fixed wing crews, though in the absence of ejection seats, flight recorders and cockpit voice recorders, the evidence is often circumstantial.(1) Both types occur, the unawareness of error type (Type I) or the awareness of conflicting inputs type (Type II).(2) The unique ability of the helicopter to hover, fly sideways and fly backwards introduces another dimension in that disorientation can occur in the hover.

10. The major types of orientation error accident can best be illustrated by brief descriptions of selected accidents:

a. In Flight Night. A newly qualified pilot with two passengers took off at night with good visibility but no moonlight. The sortie called for ground illumination with searchlights. On route to the search area the pilot realized how dark the night was, and turned out to sea to ensure safe terrain clearance. Within 5 minutes of take off the aircraft crashed at cruise speed into a headland killing all 3 occupants. No mechanical or technical cause of the accident was elicited. No distress radio call was made, but one call was made when the pilot elected to transit over the sea. (Classified as a Type I unawareness of error accident).

b. In Flight Night. A pilot with one passenger took off at night, with a cloud base of 1000 ft and good visibility beneath the cloud. The aircraft followed a track over steadily rising ground. Five minutes after take off an inadvertant cloud entry took place and the pilot commenced a 180° turn. The aircraft descended in the turn, collided with high tension cables and distintegrated, killing both occupants. No radio calls were made to the airfield of departure which had full RT and radar services. It is not possible to classify the accident as Type I or Type II, but a night cloud entry with a 180° turn are classic ingredients of a Type II disorientation accident.

c. In Flight Day. A solo pilot was on route to his base in good visibility when he observed suspicious ground activity. He commenced a descending right turn to observe the activity and after a 180° turn flew into the ground at 110 Kts and was killed instantly. A detailed investigation convincingly determined that a Type I error had occurred.

d. Hover Day. A pilot was approaching a snow covered but bare hilly area to land on an overcast day with occasional snow flurries. The first awareness of error the pilot realized was that, as he thought he was approaching the landing spot was slowly decaying forward speed, he impacted the snow with 25 Kts sideways speed and the helicopter rolled over. The pilot and passengers were uninjured. There were no orientation cues in the area apart from a vehicle and a few trees. The vehicle was parked on a slope and the trees were not growing vertically. The pilot perceived the vehicle to be level and at a sub threshold rate began to drift sideways during the final part of the approach. (Type I error).

e. In Flight Night-Special Equipment. A pilot using passive night vision goggles was flying a standard circuit pattern at night. On the downwind leg he failed to notice a gentle descent commencing. Just before ground impact, he became aware of the ground and made a heavy, fast landing in a soft field, fortunately with no injuries. (Classified as a Type I accident).

f. In Flight Night. A very experienced solo instructor pilot took off on a dark night with good visibility from a jungle clearing. A right hand circuit was in use. After climbing to 500 ft AGL the aircraft was seen to commence a left turn and to descend gently. The descending turn continued until tree impact occurred, killing the pilot. There were no orientation cues in the area until a height of 1500 ft was reached, when village lights and fishing fleet lights could be seen at some distance. A detailed investigation took place and no technical or medical causes were determined. Flight testing over the exact track of the aircraft was able to reproduce consistently the Type I (unwareness) error in the other unit pilots that almost certainly took place.

11. Several Type II accidents have occurred, most being inadvertant cloud entry immediately after take off in poorly instrumented aircraft, resulting in a survivable accident. Some operators have had Type II accidents in which the pilot has transmitted his predicament prior to fatal ground impact. This has not occurred in Army helicopter operations. It has not been possible to reliably categorize the 28 accidents as Type I or II. However three incidents are described that illustrate different Type II disorientation effects:

a. In Flight Night. A solo inexperienced pilot with no instrument rating and limited instrument flying training was number two in a two ship formation. Having been transported to a new location with their helicopters in a large transport aircraft, the helicopters were prepared for flight and a positioning flight undertaken at short notice. The number two was unfamiliar with the area and was simply briefed to follow the number one. On route the number two inadvertantly entered cloud and lost contact with number one. Within seconds he was totally disorientated with severe conflicting sensations. His own graphic description states "I centralized the controls and prayed, whilst seeing images of my life flash before my eyes". He did not lose total control of the aircraft, and he broke cloud in a fast descent with a steep angle of bank and minimal airspeed. He was in a well populated area and managed to re-orientate himself with difficulty using street and house lights for reference. He recovered the aircraft and returned to his departure point. The subsequent intense phobic anxiety took many weeks to resolve.

b. In Flight Day. An experienced pilot, on conversion from one aircraft type to another was noticed by his instructor to lose aircraft control in a slow manner at altitude. The instructor aborted the sortie and returned to base. The student described a classic break off phenomenon. After several minutes of cruising straight and level at 4,000 ft he became aware of total dissociation. He could see his hands, feet, controls and instruments as if through a glass window and could do nothing to control them. He was aware of the aircraft departing from controlling flight. He had experienced similar but less severe sensations on his original aircraft type, but had never lost control. Despite intensive training and counselling the sensation continued to occur at altitude and on instrument flying training. He gained a limited qualification on type and completed his military flying career without further incident.

c. In Flight Day. An experienced helicopter pilot was flying a fixed wing aircraft solo at altitude and on descending he cleared his middle ears (Valsalva manoeuvre). He experienced intensive vertigo and a visual illusion of rolling movement. By forcibly reverting to instrument flying (it was a sunny, clear day) he maintained straight and level flight. He estimated that it took 3-4 minutes to regain his normal senses. He then landed normally at his base. No pressure vertigo incidents have been reported in helicopter operations, though it is reasonable to assume that the normal incidence (10-17%) occurs.

12. Accident record analysis shows Type I errors to be the most common. However in fatal accidents, it is difficult to categorize the errors. In Type I errors, no radio call would be made due to the unawareness of the situation, and in Type II situations the stress of the conflicting sensations is not conducive to making radio calls. Coning of attention, freezing at the controls or panic may overwhelm the pilot in these cases.

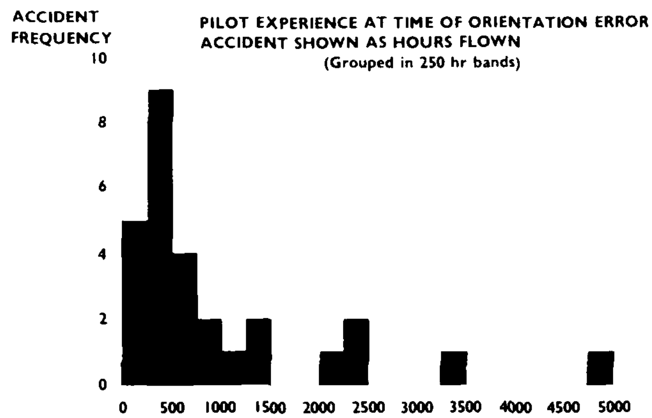
FACTORS INFLUENCING ORIENTATION ERROR

13. To list all the factors of significance is not practical. Such a list would cover, in principle, most of the factors involved in fitness for flight, and has been well documented previously.(3) The factors relevant to Army helicopter operations are considered. It must be borne in mind that the Army operates from field locations and that the tactical flying environment is low level, at tree top height or below. In peacetime operations, such as internal security and training exercises, flight at higher altitudes takes place with the normal ceiling being 5000 ft.

a. Aircrew Factors

(1) Experience. The 28 accidents classified as orientation error were subjected to a pilot flying hours study. Grouping pilot experience in bands of 250 hours, the frequency distribution of the accidents is shown in Fig 3. The distribution shows a marked bias to the inexperienced pilot. Expressed as percentages the pilots who had the 28 orientation error accidents can be grouped as:

Less than	250	hours	-	18%
"	"	500	"	-	50%
"	"	750	"	-	64%
"	"	1000	"	-	71%



PILOT EXPERIENCE AND ORIENTATION ERROR ACCIDENT FREQUENCY

Fig 3. Pilot experience and orientation error accident frequency

However the distribution of flying hours of all pilots follows the same trend as the accident distribution. It is not possible with such small numbers and with the non-availability of all pilots hours at the time of each accident to determine any statistical correlation. The newly qualified pilot will arrive in his unit with just over 200 hours and it is the 250-500 hour group that has the greatest number (9 or 32%) of orientation error accidents.

(2) Instrument Flying Training. Considerable discussion for and against instrument flying training has taken place over the years and it is only relatively recently (1977) that all helicopter pilots have received training to a rating standard. Consequently it is not possible to determine over an 18 year period with differing aircraft capabilities and aircrew training, the significance of any difference between rated and unrated pilots involved in orientation error accidents (see Table 2).

TABLE 2

INSTRUMENT FLYING
RATED AND NON RATED PILOTS IN ORIENTATION
ERROR ACCIDENTS

INSTRUMENT FLYING RATED AND NON RATED PILOTS IN ORIENTATION ERROR ACCIDENTS

	RATED PILOTS INCL LAPSED RATINGS GROUP	UNRATED PILOTS GROUP
ACCIDENTS	8 (29%)	20 (71%)
FATALITIES	6 (33%)	12 (67%)

All agencies are agreed that instrument flying training provides a skill essential to every military aviator. This is emphasised when 18 (64%) of the orientation error accidents occurred after inadvertant cloud entry, in fog or in snow storms, when instrument flight recovery was the only viable alternative to the accident. The mismatch between training and task causing the discussion is that the military tactical flying task does not require regular IMC operations.

(3) Disorientation Training. Army aircrew receive classroom instruction during their basic flying course. This is conducted by the Royal Navy and incorporates a spin chair device similar to that described in paper B12. Refresher training takes place on conversion courses and at unit locations, using a simplified spin chair that is easily transportable and very effective.

(4) In Flight Disorientation Training. This is not undertaken at present as a set sortie. Instructors demonstrate sub threshold manoeuvres and recoveries from unusual altitudes during the basic fixed wing part of the flying course and again during the instrument flying training phase of the advanced helicopter part of the course. The content varies from instructor to instructor. A demonstration sortie has been developed recently that is currently undergoing evaluation. In the sortie, a Specialist in Aviation Medicine (Flight Surgeon) current on the aircraft type, with 3 students, flies a set pattern of manoeuvres with appropriate briefings and commentaries by the students and the Specialist. Details of the sortie are at Annex A. If the evaluation is satisfactory the sortie will be included in the advanced helicopter phase of the flying course.

(5) Two Man Crew. Until recently most operations were single pilot, with an observer present if available. This situation has been reversed and now the majority of operational sorties are conducted with a pilot, and an observer trained to a more proficient level of flight skill. Consequently flight management and task management can be monitored on a shared workload basis, with a reduction in pilot workload. Two pilot crew operations are currently being studied and may be introduced for certain operations.

(6) Physical and Mental Health. Education on the effects of illness, fatigue, drugs, alcohol etc is undertaken on the basic flying course. Regulations regarding duty time and rest periods are published for commanders and unit personnel. Fatigue increases susceptibility to disorientation and can be determined as a factor in most of the accidents considered, though it cannot be quantified.

b. Aircraft Factors

(1) Instrumentation. During the period under study, aircraft instrumentation has improved dramatically. Some helicopters did not have an attitude indicator and, even when one was fitted on modification to one aircraft type, only one minute of instrument flight was allowed. All helicopters now have a standard flight instrument panel and one recently introduced type has an automatic flight control system, with height and heading hold. A full flight director/auto pilot system is available for helicopters, but is not being considered for Army use at present. The significance of these systems is obvious when it is realized that helicopters are unstable and cannot be trimmed for hands off flight without a stability system. Consequently an inadvertant cloud entry requires the pilot to fly the aircraft with total concetration. A simple task such as a radio frequency change can be hazardous. The retrospective fitting of a stability system is about to take place in our light observation helicopter, as is the fitting of a radar altimeter. Height management and ground proximity warning will be significantly improved as a result.

(2) Performance. Modern helicopters can sustain significant acceleration levels, but are not cleared for service operation to these levels. Rapid head movements during manoeuvres will induce the cross coupled phenomenon and, as with other aircraft types, aircrew rapidly learn their acceptable head movement rates subconsciously. Vibration, although present in many flight phases, is not severe enough to make the instruments unreadable in Army helicopters.

(3) Display Position. This has received more attention in recent years and has improved considerably. One aircraft type in service still has one radio to the rear of the pilot's left elbow requiring large head movements to allow tuning and adjustment. This has caused at least one accident. Two crew operation would reduce this hazard as would re-location. However the main instrument panel area is slowly becoming more cluttered as more aids are introduced.

(4) External View. A variety of problem areas exist here. The helicopter's manoeuvrability calls for all round vision and cockpit structures cause many blind spots. It is not possible to provide wipers that sweep large enough areas or adequately sweep curved surfaces. Internal misting readily occurs and is not easily dispersed in some aircraft types. Slow speed or hovering flight allows droplets to form on the screens which will only disperse at high speeds. In poor weather conditions this can cause problems as high speeds are undesirable, particularly at low level.

(5) Special Equipment. Two equipments have been involved in orientation error accidents. Passive Night Vision Goggles have been involved in 2 accidents, one previously described (para 10.e.) and one resulting in 2 fatalities. Strict training and operating procedures are applied to the use of these goggles as external vision and instrument scan are adversely affected. One accident occurred following a night inadvertant cloud entry in an aircraft operating a very powerful searchlight. The brilliant cloud illumination was followed by the searchlight being switched off and a steady descent into the ground, with fatal results. The loss of night vision must have been a major factor in the disorientation that resulted. With both equipments disorientation refresher training is advocated.

c. Environment Factors

(1) Weather. As mentioned previously 18 of the 28 accidents occurred following cloud entry, flight in fog or in snow. The military ground task is not weather related and aborting the sortie must be considered at the briefing stage in poor conditions. Flight planning in field locations may not provide up to date information. Instrument flight recovery is not always practicable in that suitably equipped diversion airfields are not always available in the area of operations. Again careful briefing pre-flight is necessary.

(2) Snow/Sand. The well known problems of flight over snow are obviously present, but added to this is the problem of re-circulating snow or sand on take off and landing. Towering take-offs, zero/zero landings and other appropriate techniques must be practised to minimize orientation error risk at critical flight phases.

(3) Sea. Army helicopter operations do not normally involve over-sea flights, apart from the occasional positioning flight.

CONCLUSION

14. Orientation error accidents have been described, showing that the inexperienced pilot is more at risk. 15% of all helicopter accidents are in the orientation error category, causing 34% of all fatalities in the period covered. The relevant factors are considered and the introduction of stability systems and radar altimeters supported. This will significantly assist the height management essential to reduce the Type I (unawareness of error) accident rate, which provides the majority of the orientation error accident group. Finally the in flight disorientation demonstration sortie under study has been described. A significant improvement in aircraft and instrument flying training has taken place in the past 3 years and a further review of disorientation in Army helicopter operations will be undertaken in 1983 to determine the effects of these changes upon the orientation error accident rate.

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ANNEX

IN FLIGHT DISORIENTATION DEMONSTRATION SORTIE

GENERAL

1. The sortie is flown with a Specialist in Aviation Medicine (Flight Surgeon) current on the helicopter type occupying the captain's seat. Three students can be flown on each sortie, one in the copilot's seat and two in the passenger seats. The aircraft flown is the current in service light observation helicopter, in which the students will become operational pilots. The sortie has been adapted and modified from those described in Agard Report No 625.

PRIOR TRAINING

2. The students will have 150 hours basic fixed wing and basic helicopter experience with a limited amount of instrument flying training. They will have completed the classroom aviation medicine and disorientation training 2-3 weeks prior to flying this sortie. Advanced helicopter instrument flying training commences at this stage also.

BRIEFING

3. As the aim of the sortie is to discuss the demonstration in the aircraft a detailed brief is not necessary. A general re-assuring briefing is held, stating that no violent manoeuvres will be flown; only one student will have his eyes shut at any one time for no more than one minute and that a running commentary is required of the subject.

4. Whilst undertaking pre-flight checks and then transiting to the area to be used a revision discussion on the use of the special senses is held.

FLIGHT MANOEUVRES

5. a. Straight and level flight is established at 100 kts. The student in the copilot's seat is asked to sit free of the controls and close his eyes when briefed to do so and give a running commentary on the aircraft attitude. The rear seat students are asked to observe but not comment until after the manoeuvre. The student is then asked to close his eyes. After 10 seconds a gently increasing roll is commenced at the same airspeed and height to 30° bank. This is stabilized and after 15 seconds the aircraft is rolled wings level. (Sensation - the roll is normally detected and as the oculogyral reflex decays a return to straight and level flight is perceived. Then a roll in the opposite direction is perceived as the roll to level flight is made). An estimate of the new heading is asked for, before the eyes are opened. Varying amounts are offered normally in excess of the true amount. Total time of eyes closed for the manoeuvre is 45 seconds. The observing students are asked for their comments.

b. Straight and level flight is established at 100 kts and one of the rear seat students asked to close his eyes. The aircraft is flown straight and level with no alteration of height, leading or speed. All students perceive climb, descents or turns in unpredictable and varying amounts.

c. Straight and level flight is established at 100 kts and the third student closes his eyes. This manoeuvre is best conducted at 500' AGL. A sub threshold descending turn is commenced as gently as possible and within 30 seconds in the particular helicopter used it is possible to lose 500 ft in height and turn through 180°. The student, remembering the second demonstration firmly states that he is straight and level. When the aircraft is established in low level flight the student is asked to open his eyes and report his heading and height. This demonstration forcibly and convincingly demonstrates a Type I orientation error, due to the proximity of the ground.

d. Straight and level flight is established at 100 kts and, upon eyes closing, the helicopter is showed rapidly, with no change of heading or height, to a high hover. The marked pitch up convinces the student that a climb is taking place often with a falsely perceived turn included when balance variations are made to keep straight. The reverse of this can be flown from a slow speed to maximum cruise speed with diving sensations perceived. (Oculogravic reflex).

e. Straight and level flight is established at 100 kts, the eyes are closed and the aircraft dived to a 20° nose down altitude. A steady pull up to 30° nose up is then made with a gentle bunt recovery. Most students perceive a continuing full loop, some experience a barrel roll sensation.

f. Hovering at 10 ft. In turn the three students are exposed to a variety of movements including a towering climb to 150 ft, sideways and backwards flight at 10 ft or slightly higher, and a landing Most manoeuvres in the hover in the helicopter used are sub-threshold and a wide range of movements are reported, all totally inappropriate. In particular the landing exercise is most convincing as the student does not realize the slight aircraft movement on landing is ground contact. These have the most educational effect upon the observing students, and are discussed in the context of snow, sand and night operations.

g. In steep turns each student in turn is invited to perform rapid head movements in pitch or yaw to experience the cross coupled phenomenon.

DE-BRIEFING

6. The different illusions, the significance of the sub threshold manoeuvres and other sensory information cues are discussed on return to the base airfield.

TIMINGS

7. The sortie can be completed in 20 minutes flight time and so can cover 18 students in 2 hours. It is economical in time in being able to fly students together, and it is particularly educational for the observing students.

CONCLUSIONS

8. It is not necessary for the copilot student to have his hands on the controls. In fact experience has shown that the sensations described are achieved quicker and with greater intensity with 'hands on', as the student is concentrating on his hands as well as other sensations and confusion occurs more rapidly.

9. Three groups of subjects have been identified in trial sorties flown so far. The groups are:

a. Experienced Aviators on Type. These aviators can maintain orientation from information such as engine noise, blade noise, aerodynamic noise, light variations, blade flicker, harness pressure etc. However orientation is lost after 20 seconds on average.

b. Student Aviators on Type. As would be expected orientation is lost more quickly within 10-5 seconds.

c. Experienced Aviators Current on Other Types Only. This group is variable, some being able to maintain orientation for 15 seconds or more, others losing it within 5 seconds.

10. It is intended to fly the sortie with students for a trial period and assess the results in a longitudinal survey. With the introduction of a helicopter flight simulator to service recently it is also intended to investigate the possibility of introducing a disorientation demonstration into it's syllabus. However the main aim of the sortie described is to reinforce in a real environment the ground training received, with a subsequent increased awareness by the trainee pilots and a reduction in the orientation error accident rate.

DISCUSSION

UNDERWOOD-GROUND

I found Col Edgington's paper most informative but was surprised and somewhat disturbed to learn that 34% of fatal helicopter accidents were attributable to pilot disorientation. The difficult problem as I see it as an aviation pathologist, is in attributing a wholly fatal, unexplained accident to disorientation. As the speaker and others have pointed out, this conclusion can be based only on circumstantial evidence.

My question is: How many accidents, labelled as Pilot Error, were covering disorientation? Personally, I feel that an accident due to disorientation should not be attributed to pilot error.

AUTHOR'S REPLY

I agree that it is unsatisfactory to reach a conclusion by exclusion, but at present once all other factors have been investigated and, in turn, excluded, then it is not unreasonable in certain accidents to come to the conclusion that orientation error was the primary cause. I would stress that doubtful cases, such as when inadequate investigation took place or when the aircraft was not recovered, were not included in my series. In answer to the question: all the cases would have been included in the Aircrew Error group. It is hoped that better investigation will provide Boards of Inquiry with more specific information, though it is unfortunate that in the past Boards of Inquiry have not called for expert opinion, especially when human factors were involved.

GUEDRY

I wonder if there has been any attempt by AGARD to develop an agreed classification of accident causation; in particular to reach an accepted classification of disorientation? This passed through my mind yesterday when listening to the paper of Voge & Miller where 'Error of judgement of speed and distance' was classified separately from 'spatial disorientation'. While I can imagine situations in which such perceptual errors would not imply that the aviator was disorientated, more often than not I would expect him to be suffering from spatial disorientation. I think there is a real need for clarification of definitions and agreement concerning the terms employed.

AUTHOR'S REPLY

I agree that a better detailed and better defined categorisation of accident causation is required. It could be most useful especially if it led to greater uniformity and comparability of the accident statistics gathered in the various NATO countries.

PERDRIEL

To the best of my knowledge AGARD has prepared no formal classification of the causes of aircraft accidents. There is, of course, the broad classification of (i) Technical Failure, (ii) Human Error, and (iii) Cause not determined. What is needed is a more detailed breakdown, and accepted definitions of the terms employed, in the Human Error category.

ILLUSIONS OF ATTITUDE AND MOVEMENT DURING EARTH-HORIZONTAL ROTATION[1]

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SUMMARY

It has been reported that, when rotated with eyes closed at constant velocity about an Earth-horizontal axis, with the body's Z-axis, aligned with the rotatory axis (barbecue spit stimulation), most subjects perceive the bodily motion to be a translation about a circle without any rotation (ferris wheel illusion). The present study of horizontal-axis rotation included aligning the body's X head axis or Y head axis with the rotatory axis, and it also included trials in which the subject was permitted to see the illuminated inside of his capsule. Analogous ferris wheel illusions were found in the X-axis and Y-axis trials, and also with internal vision permitted.

INTRODUCTION

During constant-velocity rotation about a vertical axis, in darkness, a subject has no perception of motion. The explanation for this is simple. The semicircular canals are sensors of angular acceleration and are not, therefore, stimulated by rotation at constant velocity. Once the effects of the initial acceleration have disappeared, the subject has the impression of being perfectly motionless.

If the axis of rotation is now set to be Earth-horizontal, the subject will perceive bodily movement during constant-velocity rotation in darkness, regardless of the subject's orientation to the rotatory axis. If, however, the subject's Z head axis is coincident with the axis of rotation, the classical "barbecue spit" rotation is realized. The perceived movement does not, however, reflect the real movement, no matter what knowledge the subject may have about the real movement. Instead, rotation at a constant velocity about a horizontal axis produces an illusion of movement (not rotation) as well as an associated postural illusion. Logically, the origin of these illusions can be ascribed to the constant reorientation of the gravitational vector acting on the gravity receptors. The specific roles played in these illusions by the various gravity receptors, most especially the otoliths and the cutaneous receptors, however, is difficult to assess.

Many illusions involving the otoliths have been identified, both in the laboratory and during flight (15). The oculogravic illusion is a typical example in aeronautics. There is little chance that the exact illusions of movement and posture which occur during horizontal-axis rotation will ever be encountered during normal flight. Their underlying mechanisms, however, are probably quite similar to those causing such illusions as the inversion illusion in parabolic flight, and the postural sensations in periods of weightlessness. It is because of the likelihood of similarities in the underlying mechanisms, that the present study was undertaken.

The purpose of this experiment was to study in a systematic manner the effects of rotation about the horizontal axis while varying the subject's head axis (as defined by Hixson, Niven, and Correia (9)), which coincides with the axis of rotation.

METHODS

Subjects

Ten voluntary male subjects underwent the entire experimental sequence. Before the experiment began, the integrity of the vestibular and visual systems of the subjects was checked by a medical examination.

Rotatory Device

The Precision Angular Mover (PAM) is a rotatory device that can be positioned so that the axis of rotation can be horizontal (Fig. 1) or vertical. It is capable of delivering controlled angular accelerations from ± 1 degree/s^2 to ± 100 degrees/s^2 with a maximum error of ± 1 degree/s^2, and angular velocities from ± 0.5 degree/s to ± 200 degrees/s with a maximum error of ± 0.5 degree/s.

The subject was placed in the gondola with the head immobilized at the centre of the axis of rotation by a restraint system (Fig. 2). He was firmly strapped in the seat of the gondola by means of an aviation harness, with foam blocks providing additional immobilization and support. The gondola can be oriented so that the axis of rotation of the PAM coincides with the selected X-, Y- or Z-axis of the subject. It can be closed so that the subject is in total darkness, although an interior light is also available. An intercom permits constant two-way communication between the subject and the experimenter.

[1]DCIEM Publication 80-P-07

Procedure

The study of the illusions of movement and attitude encountered during constant-velocity rotation about a horizontal axis was part of a much broader experiment. The motion sickness that usually accompanies such rotation was simultaneously investigated, and the results will be published elsewhere (11a).

Each subject underwent nine separate tests of rotation about the horizontal axis. The number of tests was determined by the number of combinations of the three subject axes (X, Y and Z) and three visual conditions (no visual reference, internal visual reference, and external visual reference). In the first condition, the subject was in total darkness (NVR). We produced the internal visual reference (IVR) by lighting the interior of the gondola and asking the subject to look at a picture approximately thirty centimeters in front of his eyes. Finally, in the external visual reference (EVR) condition, the gondola hatch was left open and the subject could see the surrounding laboratory, with a visual field of about 60^0 X 50^0. The order of tests for each subject was determined by a nine by nine Latin square.

Each test lasted five minutes unless the subject became sick and asked that it be terminated sooner. The profile for each test consisted of a counterclockwise acceleration at 20 degrees/s^2 until the PAM attained a rotational velocity of 120 degrees/s (20 rpm). This velocity was kept constant throughout the test, and the rotation was stopped by a deceleration of 20 degrees/s^2.

Before the test began, the subject was instructed to carry out three tasks:

1. perform an oral calculation, which consisted of counting backward, by twos, from one thousand;

2. announce the appearance of any symptoms of motion sickness; and

3. memorize the basic characteristics of the sensation of attitude and motion perceived during the period of constant-velocity rotation.

Following the test, the subject's description of his sensations of motion were recorded on tape. On the whole, the subjects correctly carried out all three tasks (although, of course, only the third is of interest here). The use of multiple tasks, one of which (the mental calculation) was presented to the subject as the principal task, probably reduced the intensity of the illusions. However, it had the basic advantage of preventing intensive introspection during the test, which could introduce distortion into the description of the illusions. Thus, only the dominant impressions of the subject were obtained, and the major characteristics of the illusions were determined (although, sometimes at the cost of some lack of detail, mainly with regard to the perceived direction of motion). This method is, therefore, contrary in its principle to the procedures used recently in this field by some investigators (10, 11).

RESULTS

In spite of the strong visual input, convincing illusions of attitude and movement were found in the IVR condition. Similar illusions, of course, were experienced in the NVR condition. Comparable illusions occurred during the X-axis and Y-axis rotations, as well as during the (usually employed) Z-axis rotations. In most subjects, the illusions were absent in the EVR condition but, in some subjects, there was perceptible illusory movement in spite of clear visual reference to the real motion.

In the perception of movement and attitude during the NVR and IVR conditions, there are a number of constants for all three subject axes. Apart from these general characteristics, it is also possible to discern some aspects peculiar to a given axis. (In the description of real and illusory movements, two systems of coordinates have been used. Terrestrial coordinates apply to real rotational movements. Subjective coordinates apply to illusory movements. Illusory movements are always referenced to the subjective vertical and, additionally, the subject's head axis (9).)

General Characteristics of Illusions of Movement and Attitude in the NVR and IVR Conditions

It is important to note that in no subject was the real rotational movement about an axis passing through the head perceived once the effects of the initial angular acceleration had disappeared. After a few seconds of rotation, the subject perceives his orientation to gravity as relatively fixed and unchanging. The notion of up and down is very clear. The location of this perceived "down" was not systematically investigated, although there was a tendency, especially in the X-axis and Y-axis tests, for the subject to perceive himself oriented feet-down and head-up. Perceiving his orientation to "down" as relatively fixed, the subject has the impression that his capsule, with him inside it, is describing an orbital curve of amplitude and form varying with the subject and the test. The overall impression has been aptly named "the ferris wheel illusion" (3). Figures 3, 4 and 5 give the results for the three axes.

Two distinct factors are, therefore, present at this level: the perceived orientation of the body relative to a perceived "down", and a motion (translation) of the body on a circular or oval course. The body is perceived to be translating a circle (or oval) without rotating, as on a ferris wheel. The circular or oval course of motion is in a plane, and that plane is generally perceived to be vertical (i.e., the perceived plane of the motion is parallel to the perceived direction of "down"). The perceived verticality of the plane of the perceived motion is quite constant across subjects in the X-axis and Y-axis tests (Fig. 6), and this plane is not only parallel to the perceived direction of "down" but is also consistently at right angles to the head axis about which the real horizontal-axis rotation is taking place. (Various orientations of the axis of rotation with respect to the subjective vertical were observed during the Z-axis rotations.)

The perceived orientation to the perceived "down" here defined as the angle between the Z-axis of the body and the subjective vertical, varies somewhat from one subject to another for a given test configuration (i.e., IVR, X, Y, Z, etc.). We can arbitrarily set down a reference system for perceived attitude with two sets of planes, one passing through the vertical axis that is perceived by the subject, the other perpendicular to that subjective vertical (Fig. 7). In this reference system, a given subject usually maintains a fixed attitude throughout the illusion. The variations in attitude observed from one subject or test to another all have a common characteristic. They occur in the sagittal plane of the subject's body (i.e., the XZ plane) no matter about which subject axis the rotation occurs.

These two elements of movement and attitude when referred to the reference system of the subject, appear superimposed in the global illusory perception of the orbital pattern. Each element, however, varies in an apparently independent manner (cf. Tables 1, 2 and 3).

The characteristics defined above are applicable in most cases of illusions occurring during rotation about a horizontal axis. This appears to be a particularly reliable characteristic for the X- and Y-axes of rotation, under the circumstances of the experiment here. These general ideas are also valid for the Z-axis of rotation but it appears to be difficult to describe the illusions for that axis of rotation. For that reason, we must now consider the individual characteristics of rotation about each of the three axes.

Special Characteristics of the Illusions According to the Axis of Rotation

Apart from the common elements, we can discern, depending on the subject's head axis, significant variations in the patterns of the perceived orbital movements as well as in the perceived orientation of the body relative to the subjective vertical.

During rotation about the Y head axis, the real plane of rotation (vertical, in the subject's XZ plane) coincides with the subject's perceived plane of orbit (also in the XZ plane). For this axis, four varieties of orbital movement were perceived:

1. elliptical movement, with the major axis experienced to be vertical;
2. elliptical movement, with the major axis as horizontal;
3. circular movement; and,
4. triangular movement.

Table 1 shows the distribution of the perceived illusory movements in each of these categories. As well, four different subjective attitudes of the body were reported: sitting upright, leaning back, leaning forward, and upside down (approximately). Figure 8 summarizes the data from Table 1. For a simplified point of view, we look at only two sets of attitudes as represented on the trigonometric circle in Figure 8. One, from 0 to π radians, corresponds to the head-up sensation and the other, from π back to 0 radians, corresponds to the head-down sensation. On this circle, the subjective vertical axis passes through the points, $+\pi/2$ and $-\pi/2$.

The data collected for the X head axis are shown in Table 2. There, too, four different illusory movements were observed, with five different perceived attitudes. Figure 9 indicates the distributions for the X-axis in the same way as for the Y-axis. The distribution here is less clear-cut than it is for the Y-axis, with a fairly large number of head-down sensations having been reported.

Lastly, for rotation about the Z head axis, where the axis of rotation coincides with the subject's longitudinal axis of the body, the description of the illusory movements is more variable and complex, as shown in Table 3. The perceived movement cannot be reduced to a single planar orbit. The dominant sensation is one of moving at the surface of a geometric body, the form and orientation to the subjective vertical of which vary considerably with the subject and the test. Three of the illusory movements are fairly well-defined; the fourth is less well-defined, in that pendular or linear components are present. Figure 10 summarizes the data in Table 3.

These illusory orbital movements are best described as two separate orbits, one involving the head, and the other the lower limbs. These two orbits may be either identical or different. There are obvious analogies with the illusions described for the X and Y head axes. The planes of the perceived orbital movements of the head and feet are both perpendicular to the perceived axis of rotation of the entire movement. Furthermore, the orbit described by the head has a larger diameter than that of the lower limbs. Regardless of the orientation of the resulting cone to the subjective vertical, its apex coincides approximately with the subject's feet.

The axis of rotation of the orbital movement is perceived as either horizontal or vertical. (In one case out of all the tests, it was felt to be slightly inclined (included in horizontal-axis perception in Table 3).)

Influence of the EVR Condition

The results above were obtained under NVR and IVR conditions. The introduction of an external visual reference changes the perceptions considerably. In this case, the illusion of a stationary attitude disappears in almost all subjects. The subject is aware of the Earth vertical, and perceives that the movement is about a horizontal axis. However, an orbital movement combined with a rotation of the body may be perceived. This effect has been noted by other writers (10).

DISCUSSION

The postural illusions which occur during rotation about a horizontal axis have been the subject of many studies (1, 3, 5, 7, 10, 11, 14, 16). Most of these studies basically dealt with rotation about only the Z-axis. Two possible hypotheses regarding the causative mechanism of these illusions can be suggested: an otolithic cause, or a touch and pressure sensor cause.

Meiry (14), using the data of Stone and Letko (16), which were gathered from horizontal-axis rotation of a subject immersed in water, attributed illusory movement to an otolithic cause (since touch and pressure cues were largely eliminated by the immersion in water). Experimental observations made for the Y-axis clearly revealed a very pure illusion of orbital movement. The shape of the orbit, which was circular for rotational velocities up to 20 rpm, became elliptical with an increase in frequency, and was reduced to a periodic vertical, linear movement at velocities above 55 rpm. When the subject is immersed in water, the input from cutaneous proprioceptors is very much reduced, and an otolithic origin of the illusion appears obvious. Meiry and Young (14-18), reported it as a central interpretation of signals induced by time-varying shear forces, acting on the maculae of the utricles and the saccules. This interpretation is quite consistent with the otolithic model developed by these authors (17).

The interpretation can also be presented in a slightly different manner. It is known that, in the absence of information from either the eyes or from the semicircular canals, the otolithic system cannot differentiate between linear accelerations and variations in the dynamic orientation of the body relative to gravity. In this case, the action of each resultant acceleratory vector (resultant between gravitational and linear inertial fields of force) rotates (6) on the saccular and utricular maculae simultaneously to produce signals which correspond, in simple terms, to a translation along two perpendicular planes. The sum, in time, of the two vectors defines the orbital movement. The gain and phase characteristics of the dynamic responses of the saccular and utricular maculae make it possible to explain the differences found in the orbital pattern as a function of frequency.

The observations of Guedry (7), who compared a group of normal subjects with a group of labyrinthine-defective subjects, oppose this interpretation. In fact, Guedry showed that, for low velocity rotation (10 rpm) about the horizontal Z-axis, most of the normal subjects perceive the real rotation; whereas, the subjects without labyrinths are very disoriented. These latter subjects, although conscious of their real movement, described orbital movements similar to those of normal subjects at 10 rpm, but exhibiting wide variations. On the basis of these findings, Lackner and Graybiel (9, 10) recently made a systematic study of the role of the proprioceptors in these illusions. Their experiments were conducted with a constant-velocity rotation of 30 rpm about the Z-axis. The subjects were normal and specially trained for this purpose. The authors concluded that the touch and pressure sensors played a dominant role in the origin of the illusions of movement and posture.

The present study does not settle on either of the two suggested mechanisms. It appears worthwhile, however, to further analyze certain aspects of the results.

Despite the variations encountered, there are some dominant characteristics common to all of the axes of rotation in these illusions of posture and movement. Simple logic compels us to believe that the same mechanism is at the origin of these illusions, no matter which axis is considered. It is, therefore, not reasonable to ascribe the illusion to an otolithic origin in some cases, and a proprioceptive one in others (13).

The presence of two distinct illusory elements--attitude and movement--certainly reminds one of the existence of static and dynamic elements (12) in the otoliths. However, the role played by touch and pressure information in the determination of the vertical and in the origin of some postural reflexes must not be discounted. As far as movement is concerned, the well-defined, constant character of the plane of orbit suggests that an otolithic mechanism is at work. It seems likely that pressure information is a factor in the perception of certain of the illusory orbital patterns. That is the case, for example, with triangular orbits which are often associated with slightly faulty immobilization of the body in that tactile cues are enhanced. With regard to the determination of the perceived vertical and the maintenance of a stationary attitude during the illusion, it is difficult with our present state of knowledge to advance a more precise explanation. Of the three ways of assessing the position of the vertical reference as given by Bischof (2), the compromise between otolithic and touch information seems the most plausible.

Finally, if Gundry's recent material on the detection of roll motion (8) is considered, it is possible to advance a new hypothesis. Under various experimental conditions, it appears that touch and pressure cues appreciably change the threshold of detection for roll motion. Considering the studies of Stone and Letko (16) and Guedry (6), subjects deprived of otolithic or touch information perceive the illusion of movement, even for low velocities of rotation. At the same velocity (10 rpm), normal subjects perceive the real rotation. Perhaps, therefore, at low stimulation frequencies, the combination of otolithic information and that of proprioceptive origin is necessary for the perception of real movement. Perhaps, beyond some critical frequency, the two sources of sensory information, are no longer centrally integrated, and would both contribute to the origin of one or the other of the illusions of posture and movement.

Beyond a simple description of events, the study of sensory illusions is quite complex. That is especially the case with the illusions found during rotation about a horizontal axis. Supplementary research on the detailed mechanism of such illusions still appears necessary. The importance of such research lies in the improvement of our knowledge of vestibulo-tactile interactions in the perception of movement and of orientation in space. The study of such illusions and their corollary, motion sickness, have, as well, a direct application in vestibular problems occurring in the field of space physiology.

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ILLUSION DE MOUVEMENT ET D'ATTITUDE LORS DE ROTATIONS AUTOUR DE L'AXE HORIZONTAL

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RESUME

Un sujet, soumis à une rotation à vitesse constante autour d'un axe passant par la tête, ne percevra pas le mouvement réel de rotation. Il se produit une illusion portant sur l'attitude et le mouvement, quel que soit l'axe du sujet autour duquel s'effectue la rotation. Bien que certaines variations soient enregistrées selon l'axe considéré, l'allure générale de ces illusions est très reproductible. Il s'agit de la perception d'un mouvement orbital, le plus souvent elliptique pour la vitesse de rotation utilisée (20 RPM). Au cours de ce mouvement, l'orientation du corps par rapport à la verticale déterminée subjectivement, est perçue comme fixe. A l'origine de ces illusions on peut avancer une explication faisant appel à la mécanique otolithique, ou bien, au contraire, une explication fondée sur les données de la proprioception cutanée. Il est en fait possible que les deux éléments contribuent conjointement à créer et à entretenir l'illusion lorsque l'on dépasse une fréquence critique de rotation.

INTRODUCTION

Soumis à une rotation à vitesse constante autour de l'axe vertical, un sujet placé dans l'obscurité ne perçoit aucun mouvement. L'explication de ce phénomène est simple. Les canaux semi-circulaires, capteurs d'accélérations angulaires ne sont pas stimulés par une rotation à vitesse constante. Une fois les effets de l'accélération initiale dissipés, le sujet a l'impression d'être parfaitement immobile.

Basculons maintenant l'axe de rotation de 90° de façon à ce qu'il soit horizontal. Si dans ce cas l'axe Z du sujet coïncide avec l'axe de rotation, c'est le classique "barbecue-spit" des auteurs anglo-saxons. Dans les mêmes conditions, le sujet va alors percevoir un mouvement. Le mouvement perçu, quelle que soit la connaissance que le sujet puisse avoir du mouvement réel, ne réflète pas ce dernier. La rotation à vitesse constante autour d'un axe horizontal provoque une illusion de mouvement, associée par ailleurs à une illusion posturale. A l'origine de cette illusion, il est logique d'incriminer la réorientation constante du vecteur gravitaire agissant sur les gravi-récepteurs. La part respective prise dans ces illusions par les différents gravi-récepteurs, et tout particulièrement les otolithes et les récepteurs cutanés, est beaucoup plus difficile à estimer.

De nombreuses illusions impliquant les otolithes ont été mises en évidence, aussi bien en laboratoire qu'au cours du vol (16). L'illusion oculogravique constitue un exemple type en aéronautique.

Les illusions de mouvement et de posture survenant lors des rotations autour d'un axe horizontal, n'ont que peu de chance de se rencontrer en vol. Toutefois par leurs mécanismes, elles sont sans doute assez proches de certaines illusions comme "l'illusion d'inversion"lors des transitions en vol parabolique, et les sensations posturales lors des séjours en impesanteur. C'est à ce titre que leur étude nous intéresse ici.

La présente expérience a pour but d'envisager d'une manière systématique les effets des rotations à vitesse constante autour de l'axe horizontal, en faisant varier l'axe-sujet (défini par HIXON et Coll. (9)), qui coïncide avec l'axe de rotation.

METHODES

Dix sujets volontaires, de sexe masculin, ont subi l'ensemble du protocole expérimental.

Avant le début de l'expérience, l'intégrité des systèmes vestibulaire et visuel a été vérifiée par un examen médical.

MOYEN DE STIMULATION

Le P.A.M. (Precision Angular Mover) est un système tournant qui peut être positionné de façon à ce que l'axe de rotation soit horizontal. Ce système permet de délivrer des accélérations angulaires contrôlées depuis 1 deg. S^{-2}, jusqu'à 100 deg. S^{-2}, avec une erreur maximum de $\pm$ 1 deg. S^{-2} et des vitesses angulaires allant de 0,5 deg.S^{-1} jusqu'à 300 deg. S^{-1}, avec une erreur maximum de 0,5 deg.S^{-1}.

Le sujet est placé dans une nacelle, la tête immobilisée par un système de contention de façon à ce qu'elle soit au centre de rotation de l'appareil. Il est fermement sanglé sur son siège au moyen d'un harnais aviation. Des blocs de mousse assurent une immobilisation supplémentaire.

La nacelle est orientable, ce qui permet de faire coïncider l'axe de rotation du PAM avec l'axe choisi, X, Y ou Z du sujet (9). La nacelle peut être entièrement close, mettant le sujet dans l'obscurité totale. Il est également possible de l'éclairer.

Un interphone permet une liaison constante entre le sujet et l'expérimentateur.

PROTOCOLE

L'étude des illusions de mouvements et d'attitude rencontrées lors des rotations à vitesse constante autour de l'axe horizontal, s'intégrait dans une expérience plus vaste.

En effet, le mal des transports qui accompagne habituellement ces illusions a fait l'objet d'une investigation simultanée dont les résultats sont publiés par ailleurs (12).

Chaque sujet avait à subir 9 tests de rotation autour d'un axe horizontal, déterminés par la combinaison des trois axes-sujet X, Y et Z, et de trois conditions visuelles (absence de vision, références visuelles fixes, références visuelles extérieures). Dans la condition d'absence de vision (NVR) , le sujet était dans l'obscurité totale. La référence visuelle fixe (IVR) était réalisée en éclairant l'intérieur de la cabine et en demandant au sujet de fixer son regard sur une photographie placée à 30 cm de ses yeux. Enfin, dans la condition avec référence visuelle extérieure (EVR), le sujet pouvait voir le laboratoire environnant sous un champ visuel d'environ 60°x 50°.

L'ordre d'application était déterminé par un carré latin 9x9. La durée de chaque test était de 5 mn, à moins que le sujet n'en demande l'arrêt prématuré en cas de malaise.

Une seule vitesse de rotation (20 RPM) était employée. Le profil de stimulation consistait en une phase d'accélération à 20 deg. S^{-2}, jusqu'à ce que le PAM atteigne une vitesse de rotation de 120 deg. S^{-1}. Cette vitesse était maintenue constante pendant toute la durée du test. Le sens de rotation choisi pour tous les essais était l'inverse de celui des aiguilles d'une montre.

Les consignes données au sujet avant le début du test portaient sur trois points :

1°) effectuer une tâche de calcul consistant à décompter de deux en deux, à haute voix et sans interruption à partir du nombre mille ;

2°) annoncer l'apparition des symptômes du mal des transports ;

3°) mémoriser les caractéristiques essentielles de la sensation de mouvement perçue pendant la rotation à vitesse constante, pour en faire un compte rendu sur magnétophone dès la fin de l'essai.

Dans l'ensemble, les sujets ont correctement accompli la triple tâche qui leur était assignée. L'utilisation des tâches multiples dont l'une, le calcul mental, était présentée au sujet comme tâche principale, atténue probablement l'intensité des sensations illusoires. Elle a toutefois l'intérêt essentiel d'éviter une introspection intensive pendant le test. En effet, cette dernière peut éventuellement introduire un certain degré de distorsion dans la description des illusions rencontrées.Aussi, nous n'avons obtenu que des impressions dominantes du sujet, permettant de dégager les caractéristiques majeures des illusions, parfois au prix d'une certaine imprécision, portant principalement sur le sens de rotation. Cette méthode s'oppose donc par son principe à des protocoles récemment utilisés dans ce domaine par d'autres auteurs (10-11).

RESULTATS

En ce qui concerne la perception de mouvement et d'attitude dans les conditions visuelles NVR et IVR, les résultats permettent d'énoncer un certain nombre de constantes pour les trois axes-sujet. A côté de ces caractéristiques générales, il est également possible de discerner certains aspects propres à un axe donné. Enfin, lorsque le sujet est en référence visuelle extérieure, l'illusion disparait dans la plupart des cas. Nous envisagerons donc successivement ces trois points.

* Caractéristiques générales des illusions de mouvement et d'attitude en conditions N.V.R et I.V.R.

Il faut tout d'abord remarquer qu'en aucun cas, le mouvement réel de rotation autour d'un axe passant par la tête n'est perçu une fois les effets de l'accélération angulaire initiale dissipés.

Après quelques secondes de rotation, le sujet perçoit son attitude dans l'espace, comme fixe, relativement à une référence verticale subjective. La notion de haut et de bas reste très nette. La nature réelle ou erronée de cette notion n'a pas été contrôlée systématiquement. Dans l'espace ainsi défini, le sujet a l'impression de décrire un mouvement orbital dont l'amplitude et la forme varient selon les sujets et les essais. Les figures 3, 4 et 5 schématisent ces données pour les différents axes étudiés.

Deux facteurs distincts sont donc déjà présents à ce niveau, le mouvement perçu et la représentation de la position du corps dans l'espace.

L'axe de rotation du mouvement orbital est généralement perçu comme horizontal. Il s'agit d'une constante vraie pour les rotations en X et en Y. Par contre, différentes orientations de l'axe de rotation, par rapport à la verticale subjective, ont pu être observées lors des rotations en Z. Dans les cas où le mouvement perçu est une orbite plane (axes X et Y), le mouvement est décrit dans un plan perpendiculaire à l'axe de rotation (fig. 6). Dans le cas le plus simple ce plan coïncide avec le plan-sujet (XY, ZX, ZY) perpendiculaire à l'axe du sujet autour duquel est appliqué la stimulation. L'axe de rotation est dans ce cas parallèle à l'axe-sujet.

L'attitude, définie par l'angle existant entre le grand axe du corps et la verticale subjective, varie d'un sujet à l'autre dans l'illusion perçue pour une configuration donnée. On peut poser arbitrairement un référentiel d'attitude par deux familles de plans, les uns contenant l'axe gravitaire perçu par le sujet, les autres normaux à cette verticale subjective (fig.7). Placé dans ce référentiel, le sujet conserve habituellement une attitude fixe pendant toute la durée de l'illusion. Les variations d'attitude observées d'un sujet ou d'un essai à l'autre ont toutes une caractéristique commune. Par rapport au sujet, elles surviennent toujours dans le plan sagittal du corps (Z, X) quelque soit l'axe-sujet stimulé.

Ces deux éléments de mouvement et d'attitude, rapportés au référentiel sujet, se superposent dans le mouvement illusoire. Cependant, chaque élément varie d'une manière apparemment indépendante (cf tableaux I, II et II).

Les caractéristiques définies ci-dessus se révèlent applicables dans la plupart des cas d'illusions rencontrés lors de rotations autour de l'axe horizontal. Ceci est particulièrement évident pour les axes de rotations X et Y, avec le cadre expérimental précédemment défini. En fait, si les idées générales énoncées restent valables pour l'axe Z, la systématisation des illusions rencontrées pour cet axe de rotation se révèle plus difficile.

C'est pourquoi il nous faut maintenant envisager les caractéristiques propres aux trois axes étudiés.

* <u>Caractéristiques particulières des illusions selon l'axe de rotation.</u>

A côté des éléments communs, on discerne selon l'axe-sujet autour duquel est appliqué la stimulation, des variations notables de la forme du mouvement orbital et de l'orientation perçue du corps par rapport à la verticale subjective.

Lors des rotations autour de l'axe Y, le plan de rotation coïncide avec le plan "attitude" (Z, X). On rencontre pour cet axe essentiellement quatre variétés de mouvement orbital :

- les mouvements en ellipse à grand axe vertical
- les mouvements circulaires
- les mouvements en ellipse à grand axe horizontal
- les mouvements triangulaires.

Le tableau 1 montre la répartition des mouvements illusoires perçus dans chacune de ces catégories. De même, quatre orientations différentes du corps ont été reconnues : assis buste droit, penché en arrière, penché en avant et enfin tête basse penché en arrière. La figure 8 reprend les données du tableau I. Dans une optique simplificatrice on ne considère que deux plages d'attitude selon un cercle trigonométrique. L'une de 0 à π correspondant à la sensation "tête en haut", l'autre de π à 0 correspondant à la sensation "tête en bas". Dans cette configuration l'axe vertical subjectif passe par les points de valeur $\frac{\pi}{2}$, $-\frac{\pi}{2}$.

Les données recueillies pour l'axe X figurent au tableau II. Là aussi, quatre catégories de mouvement ont été observées, avec 5 variétés d'attitude. La figure 9 utilise la même représentation que celle de l'axe Y. On note ici une répartition moins nette que pour l'axe Y, avec un nombre relativement élevé de sensations "tête en bas".

Enfin, pour les rotations autour de l'axe Z, où la stimulation est appliquée selon le grand axe du corps, la description des mouvements illusoires devient plus confuse et complexe. Le mouvement ne peut être ramené à une seule orbite plane. La sensation dominante est celle de se déplacer à la surface d'un volume, dont la forme et l'orientation par rapport à la verticale subjective varient selon les sujets et les essais. Le tableau III résume ces données, en distinguant trois volumes de révolutions assez bien définis et une classe moins délimitée où figure des déplacements pendulaires ou linéaires. La figure 10 reprend cette classification.

La nature du mouvement orbital peut être définie par deux orbites planes, l'une de la tête, l'autre des extrémités inférieures. Ces orbites peuvent être identiques ou différentes. Les analogies évidentes existent avec les illusions décrites pour les axes X et Y. Les plans des mouvements orbitaux de la tête et des pieds sont perpendiculaires à l'axe de rotation du mouvement. Il faut noter que l'orbite décrite par la tête est toujours supérieure en diamètre à l'orbite des extrémités inférieures. Quelle que soit l'orientation du cône résultant par rapport à la verticale subjective, l'apex coïncide approximativement avec les pieds du sujet.

L'axe de rotation du mouvement orbital peut être ici perçu comme horizontal ou vertical. Il est parfois légèrement incliné par rapport à l'horizontale subjective (1 seul cas sur l'ensemble des essais).

Ces résultats ont été obtenus dans les conditions visuelles VA et IVR. L'introduction des références visuelles extérieures modifie considérablement les perceptions. C'est ce dernier point que nous envisagerons maintenant.

* Influence de la condition visuelle EVR.

L'illusion d'attitude fixe disparait dans ce cas. Le sujet se recale visuellement sur une verticale terrestre, et perçoit le mouvement de rotation autour de l'axe horizontal. Par contre, un mouvement orbital combiné avec une rotation du corps peut être perçu. Cet effet a d'ailleurs été noté par d'autres auteurs (10).

DISCUSSION

L'étude des illusions posturales survenant lors des rotations autour de l'axe horizontal, a déjà fait l'objet de nombreux travaux (1, 3, 5, 7, 10, 11, 15, 17). En fait ces études ont essentiellement porté sur des rotations autour de l'axe Z du sujet. Deux types de mécanismes ont pu être avancés en ce qui concerne l'origine de ces illusions : une hypothèse "otolithique" et une hypothèse mettant en avant le rôle des informations tactiles et de pression.

En se basant sur les données de STONE et LETKO (17) recueillies lors de la rotation autour d'un axe horizontal d'un sujet en immersion, MEIRY (15) rattache l'illusion de mouvement à un phénomène otolithique. Les observations expérimentales, effectuées pour l'axe Y, mettaient en évidence d'une manière très nette une illusion de mouvement orbital très pure. La forme de l'orbite, circulaire pour des vitesses de rotation allant jusqu'à 20 RPM, devenait elliptique avec l'augmentation de fréquence pour se réduire à un déplacement vertical, linéaire et périodique au-dessus de 55 RPM. En immersion, où les données de la proprioception cutanée sont fortement atténuées, l'origine otolithique de l'illusion apparait évidente. Pour MEIRY et YOUNG (15-19), il s'agit de l'interprétation centrale des signaux d'origine otolithique engendrés par la réorientation continuelle du vecteur gravitaire à la surface des macules utriculaires et sacculaires. Cette interprétation est d'ailleurs tout à fait cohérente avec le modèle otolithique conçu par ces auteurs (18). Il est possible de présenter cette interprétation d'une manière légèrement différente. On sait en effet qu'en l'absence de données visuelles ou d'informations en provenance des canaux semi-circulaires, le système otolithique ne peut faire la différence entre une accélération linéaire et une variation d'orientation du corps dynamique par rapport à la gravité. Dans ce cas on peut dire que l'action du vecteur tournant gravitaire sur les macules sacculaires et utriculaires, va entraîner des signaux correspondant schématiquement à une double translation. La somme dans le temps des deux fonctions définit le mouvement orbital. Les caractéristiques de gain et de phase dans les réponses dynamiques des macules utriculaires et sacculaires, permettent alors d'expliquer les différences rencontrées dans le pattern orbital en fonction de la fréquence.

Les observations effectuées par GUEDRY (7) en comparant un groupe de sujets normaux à un groupe de sujets ayant perdu la fonction labyrinthique, viennent à l'encontre de cette interprétation. En effet, pour des rotations à faible vitesse (10 RPM) autour de l'axe Z horizontal, GUEDRY montre que la plupart des sujets normaux perçoivent la rotation réelle alors que les sujets sans labyrinthes sont très désorientés. Ces derniers, bien que conscients de leur mouvement réel, décrivent un mouvement de caractère orbital qui présentent de larges variations. Sur la base de ces constatations LACKNER et GRAYBIEL (9, 10) ont récemment étudié d'une manière systématique le rôle des données proprioceptives de tact et de pression. Leurs expériences ont été menées avec une vitesse de rotation constante de 30 RPM autour de l'axe Z. Les sujets étaient normaux et entraînés. Ces auteurs concluent au rôle prédominant des données tactiles et de pressions à l'origine des illusions de mouvement et de posture.

Notre étude ne permet en aucune façon de trancher définitivement entre les deux mécanismes proposés. Il apparait toutefois intéressant d'analyser plus en détail certains aspects des résultats.

Malgré les variations rencontrées, on retrouve dans ces illusions posturales des caractéristiques dominantes, communes à tous les axes de rotation. La logique uniciste nous conduit donc à penser que le même mécanisme est à l'origine de l'illusion quel que soit l'axe considéré. Il est donc difficile d'affirmer que l'illusion puisse être d'origine otolithique dans certains cas, et somesthésique dans d'autres (14).

La présence de deux éléments distincts d'attitude et de mouvement n'est pas sans rappeler l'existence d'éléments statiques et dynamiques (13) au niveau des otolithes. D'un autre côté, il ne faut pas sous-estimer le rôle joué par les informations tactiles et de pression dans la détermination de la verticale et à l'origine de certains réflexes de posture. En ce qui concerne le mouvement, le caractère bien défini et constant des plans de rotation incite à penser qu'un mécanisme otolithique est en jeu.
Il est par ailleurs évident que des informations de pression contribuent à l'élaboration de certains patterns orbitaux. C'est par exemple le cas des orbites d'allure triangulaire, souvent associées à une immobilisation du corps légèrement défectueuse. Quant à la détermination de la référence verticale et au maintien d'une attitude fixe pendant l'illusion, il est difficile dans l'état actuel de nos connaissances d'avancer une explication précise. Des trois modes d'estimations énoncés par BISCHOFF (2), le compromis entre les informations otolithiques et tactiles semble le plus plausible.

Enfin, en s'éclairant des données récentes de GUNDRY sur la détection des mouvements de roulis (8), il est possible d'avancer une hypothèse nouvelle. Il semble, en effet, que les données tactiles et de pression modifient sensiblement le seuil de détection des mouvements de roulis étudiés sous différentes conditions expérimentales. Considérant les données de STONE et de LETKO (16) et celles de GUEDRY (6), on remarque que les sujets privés d'informations otolithiques ou tactiles perçoivent l'illusion du mouvement, même pour les faibles vitesses de rotation. Dans les mêmes conditions de vitesse (10 RPM), un sujet normal perçoit la rotation réelle. Il se pourrait donc que pour des fréquences de stimulation basses, seule la combinaison des informations otolithiques et d'origine cutanée puisse aboutir à la perception du mouvement réel. Au-delà d'une fréquence critique, les deux sources d'informations sensorielles n'étant plus correctement intégrées au niveau central contribueraient à l'apparition de l'illusion de posture et de mouvement.

L'étude des illusions sensorielles est souvent complexe lorsque l'on veut dépasser le cadre de la simple description des phénomènes. C'est le cas des illusions rencontrées lors des rotations autour de l'axe horizontal. Des recherches complémentaires portant sur le mécanisme intime de ces illusions, apparaissent encore nécessaires. L'intérêt présenté par de telles recherches, réside dans l'amélioration de nos connaissances sur les interactions vestibulo-tactiles dans la détermination du mouvement et de l'orientation dans l'espace. L'étude de ces illusions et de leur corrollaire, le mal des transports, trouve de plus une application directe en matière de physiologie vestibulaire en cosmonautique.

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Table 1. Illusions of movement and attitude during Y Earth-horizontal-axis rotation: These results came from 10 subjects with two trials per subject (*indicates that two results were not usable). Attitude is referenced to subjective vertical (from top to bottom). Four classes of orbital patterns, based on the shape of the orbit, have been considered.

ILLUSIONS OF MOVEMENT AND ATTITUDE

Y-AXIS

MOVEM. / ATTITUDE	ELLIPSE (VERTIC.)	CIRCULAR	ELLIPSE (HORIZ.)	TRIANG.	TOTAL
	4	–	1	1	6
	1	2	1	–	4
	6	–	–	1	7
	1	–	–	–	1
TOTAL	12	2	2	2	18*

Table 2. Illusions of movement and attitude during X Earth-horizontal-axis rotation: As for Y-axis rotation (see Table 1), four classes of orbital patterns have been considered (*indicates that one test was not usable).

ILLUSIONS OF MOVEMENT AND ATTITUDE

X-AXIS

MOVEM. / ATTITUDE	ELLIPSE (VERTIC.)	CIRCULAR	ELLIPSE (HORIZ.)	TRIANG.	TOTAL
	4	3	–	2	9
	–	1	–	–	1
	1	–	–	–	1
	2	2	2	–	6
	2	–	–	–	2
TOTAL	9	6	2	2	19*

Table 3. <u>Illusions of movement and attitude during Z Earth-horizontal-axis rotation</u>: Movements are not perceived as occurring in a plane, but more like revolutions around the surface of a cone or a cylinder. The table does not take into account the variations in the perceived axis of rotation (*indicates that two successive illusions have been perceived during one test).

ILLUSIONS OF MOVEMENT AND ATTITUDE

Z-AXIS

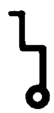
MOVEM. / ATTITUDE	ELLIPTICAL CYLINDER	CIRCULAR CONE	CIRCULAR CYLINDER	OTHER	TOTAL
 OR 	3	6	–	1	10
	3	1	1	3	8
	3	–	1	–	4
TOTAL	9	7	2	4	22 *

Fig. 1. The Precision Angular Mover (PAM): The device is set for an Earth-horizontal-axis rotation. The white cross on the gondola shows the centre of rotation. In this figure, the gondola has been set to deliver stimulation about the subject's Y head axis.

Fig. 2. Subject as he appears in the gondola prior to rotation: The gondola is oriented for X-axis rotation. Note that the position of the head restraint system is at the centre of rotation of the device. Foam pads are used to provide good immobilization of the subject's legs. The flap at the bottom of the gondola is designed to close up the system.

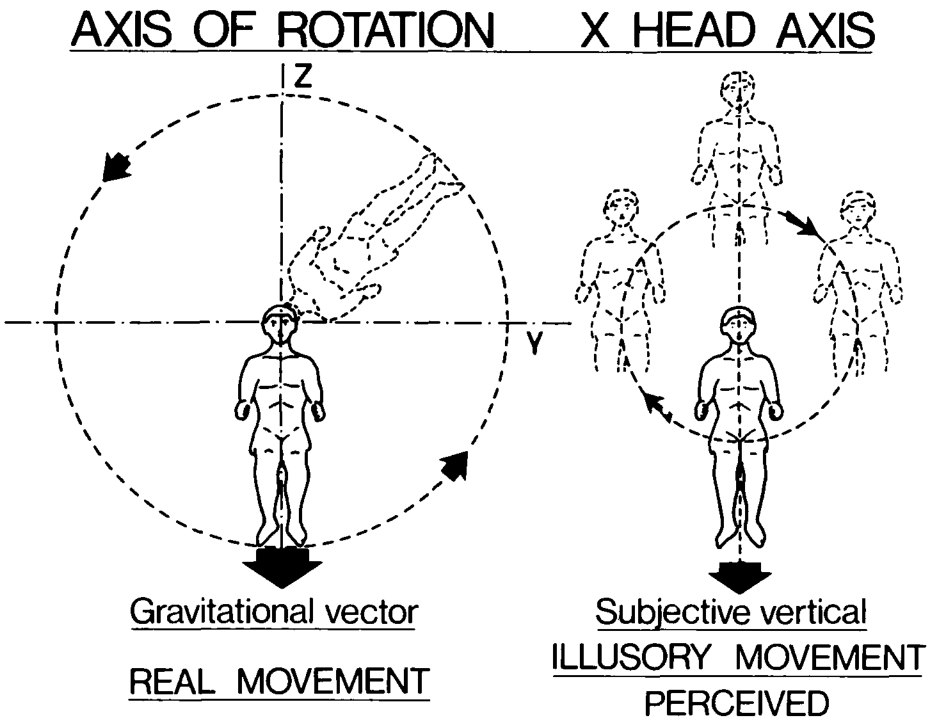


Fig. 3. Real and illusory movement about X-axis: The real movement is illustrated on the left, and the illusory movement on the right.

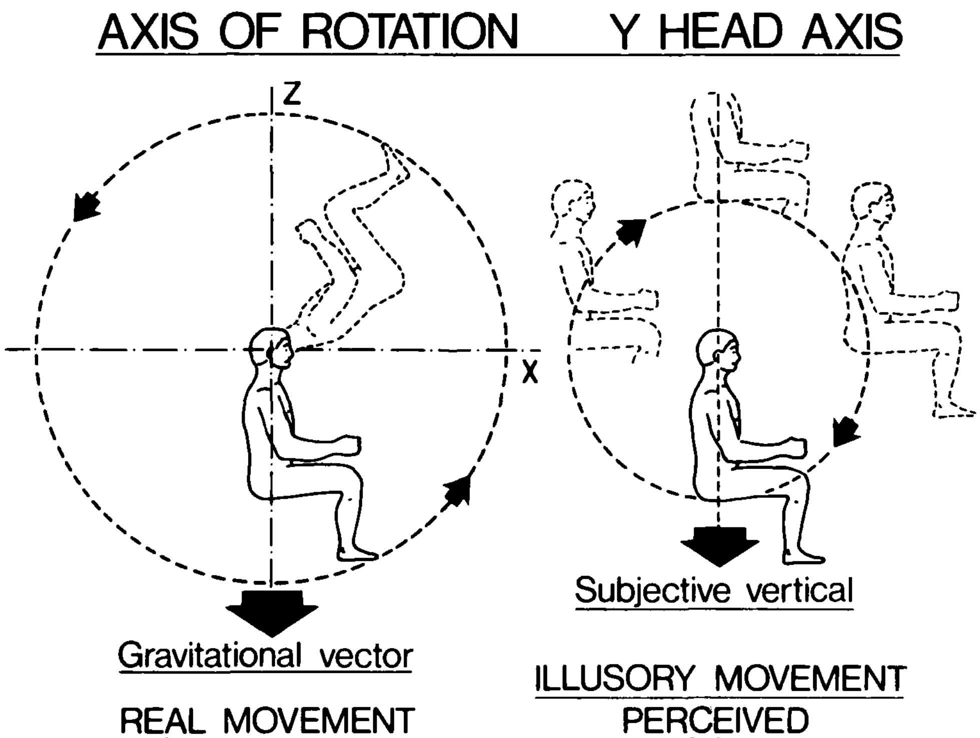


Fig. 4. Real and illusory movement about Y-axis: Movements are illustrated as in Fig. 3. The subject's plane in which the real rotation occurs is the same as the plane of perceived orbit (i.e., the sagittal plane).

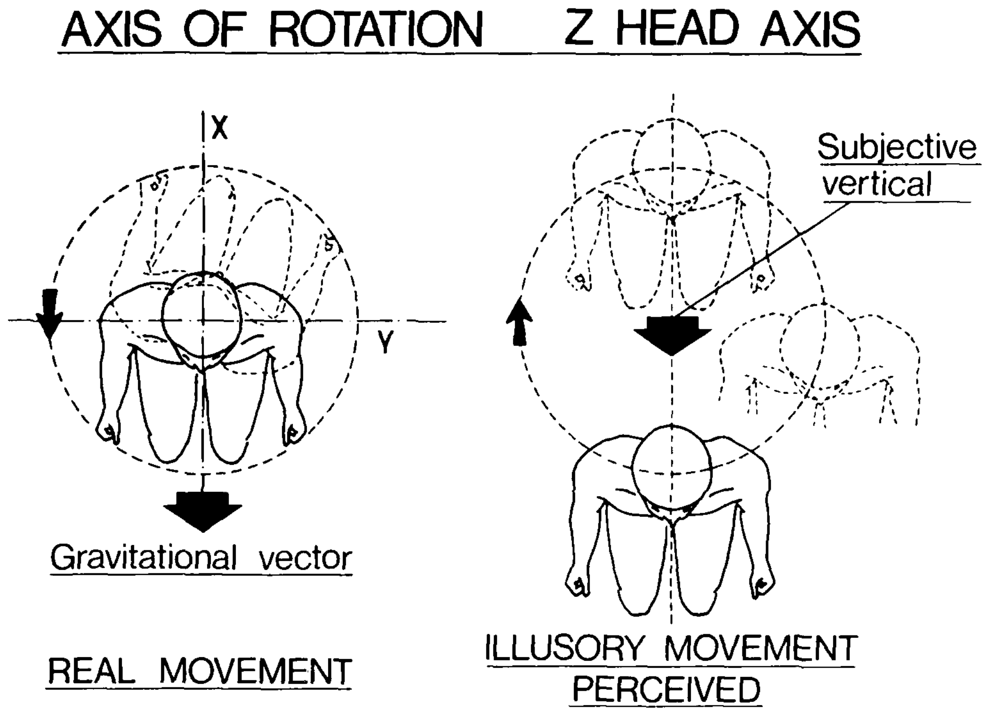


Fig. 5. Real and illusory movement about Z-axis: The rotational axis is the main (spinal) axis of the body. In this case, only the illusory movement of the head is considered.

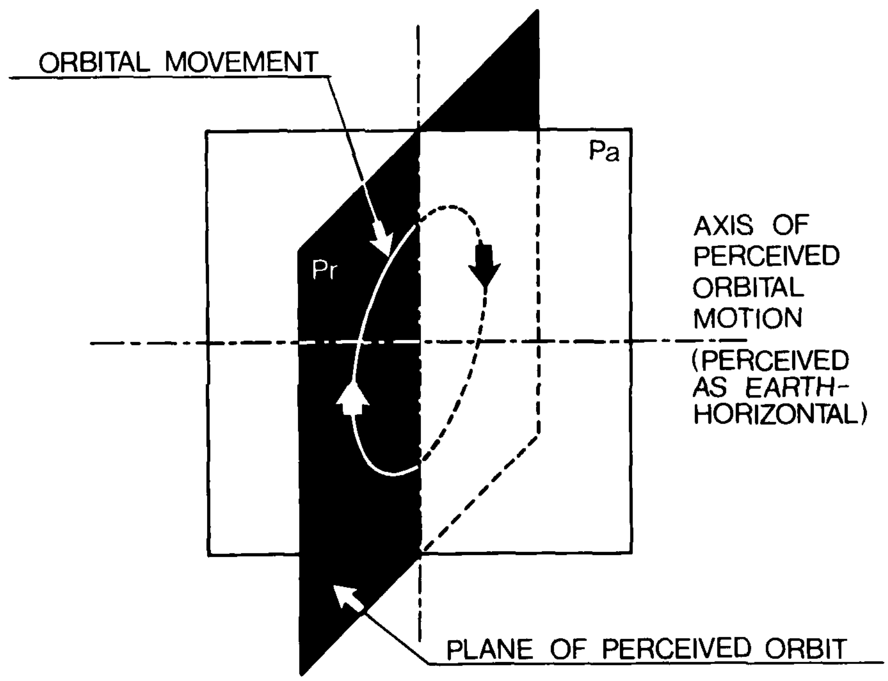


Fig. 6. Axis of perceived orbital motion and plane of the perceived orbit: The axis of rotation of the illusory orbit is mostly perceived as an Earth-horizontal one (and the plane of the illusory orbit is vertical). Some subjects perceived the plane of illusory orbit as horizontal, [illegible] Z-axis rotation. P_a and P_r are: plane in which subject perceived axis of orbital movement, and the illusory orbital plane, respectively.

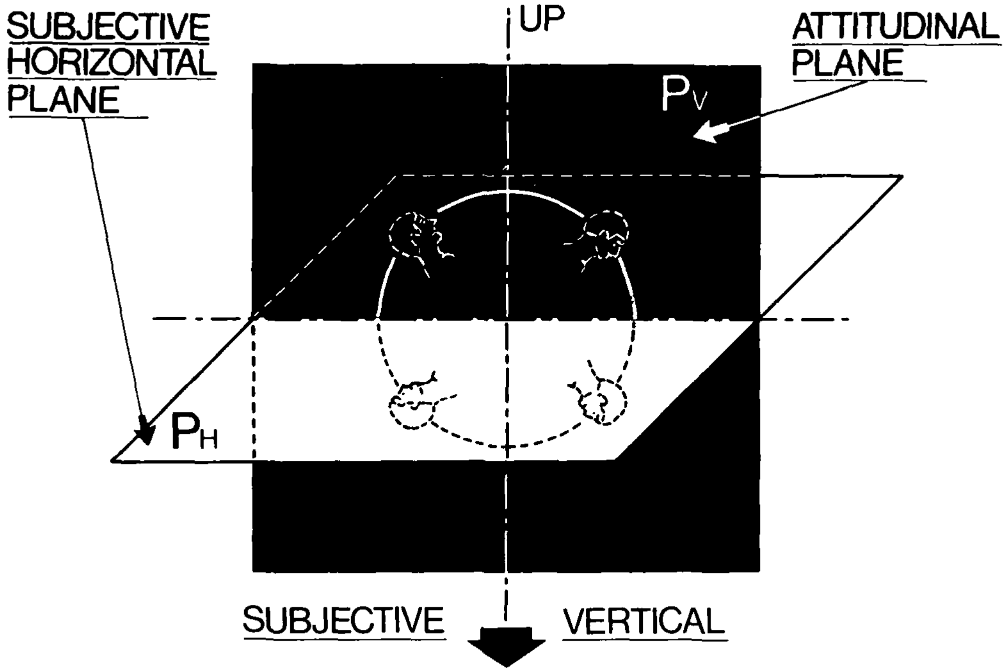
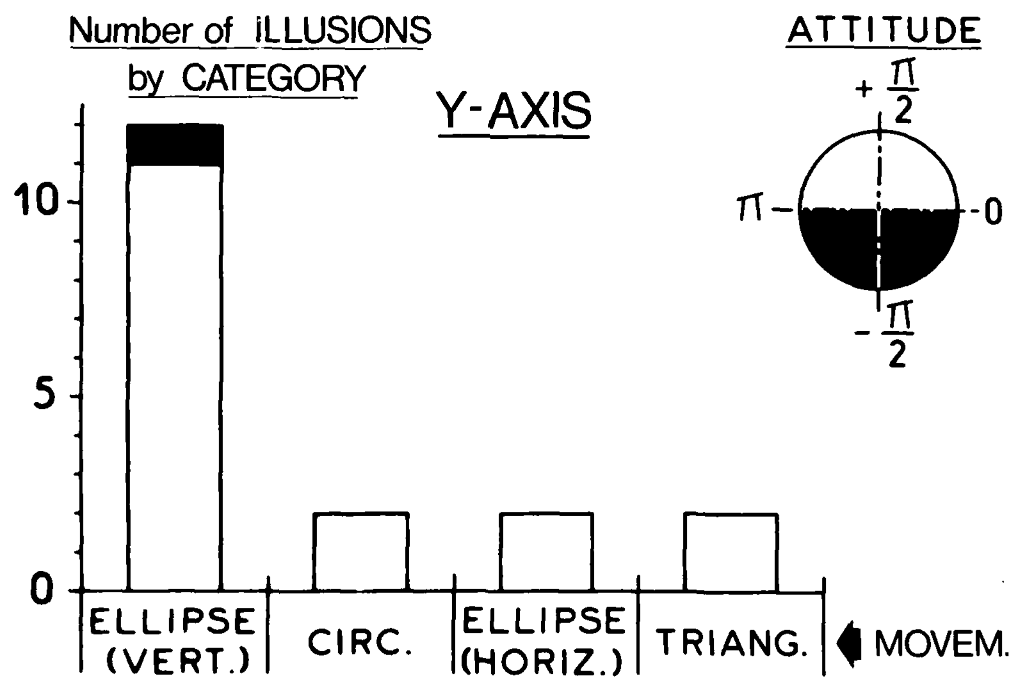


Fig. 7. Subjective vertical and representation of attitude: During the illusory movement perceived for a given trial, the angle between the subjective vertical and the subject's body remains constant. The feeling of up and down is always fairly strong. The attitude can vary from trial to trial. Variations always occur in the sagittal plane of the body, whatever axis of rotation is considered. P_V and P_H are attitudinal (vertical) and subjective horizontal planes, respectively. The subjective horizontal plane is normal to the subjective vertical.



[illegible] axis rotation: Results from Table 1 are shown [illegible] planes have been considered, viz., "head- [illegible], the attitudes from 0 to π are noted as "head- [illegible] vertical passes through the points, +π/2 and [illegible] plane" and the "rotational plane" are in [illegible] mainly illustrates elliptical patterns with major axis [illegible]

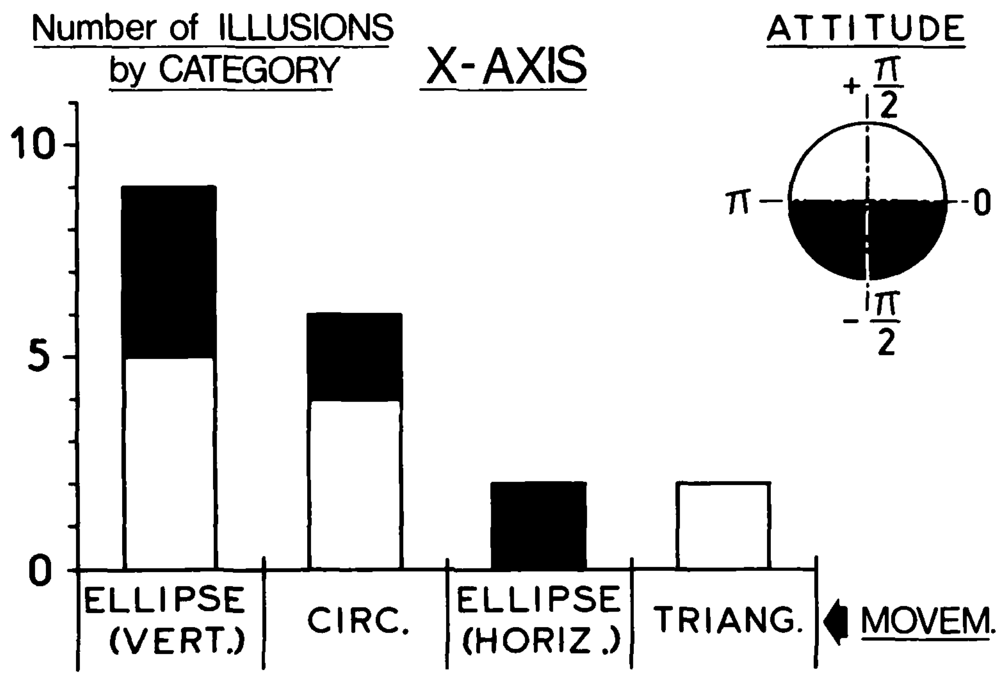


Fig. 9. Distribution of illusions for X Earth-horizontal-axis rotation: As in Fig. 8, with data from Table 2. Note that the distribution is less definitive than is that for data from the Y-axis. A large number of head-down attitudes were perceived.

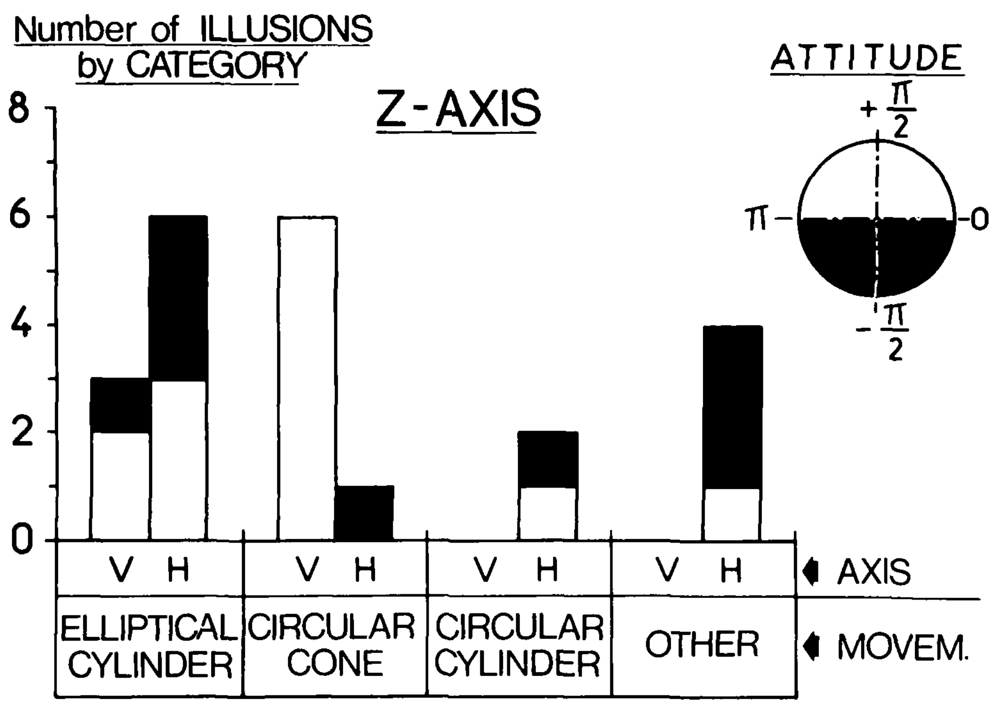


Fig. 10. Distribution of illusions for Z Earth-horizontal-axis rotation: The distribution is far more complex than it is for X-axis and Y-axis distributions. The perceived axis of rotation may be either horizontal (H) or vertical (V). A perceived vertical axis of rotation is often associated with conical orbital patterns. On the other hand, when the orbital pattern is a circular cylinder, or a cylinder with an elliptical basis, the subjective axis of rotation of the movement is mostly horizontal.

DISCUSSION

GUEDRY

Did your subjects experience the effects you describe only after the response of the semicircular canals to the initial angular acceleration had subsided? And did you study the responses at speeds other than 120^{o}/sec?

By way of comment: we studied subjects without labyrinths and they, during horizontal axis rotation at 60^{o}/sec, experienced sensations very similar to those you report for normal subjects at 120^{o}/sec. They, of course have tactile information, so it may be that somatosensory cues are more important than vestibular cues in the generation of the sensations of body motion.

AUTHOR'S REPLY

Our experiments were confined to a rotational speed of 120^{o}/sec. There is, however, clear evidence from the studies of Stone and Letko that the subjective responses are dependent upon the angular frequency. They found that at 120^{o}/sec the sensation was one of rotation in a circular orbit which became elliptical between 120 and 300^{o}/sec. Above 300^{o}/sec the sensation was purely one of vertical, up and down, linear displacement.

ORTHOSTATIC DISORDERS A CONTRIBUTING FACTOR TO MOTION SICKNESS?

by

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SUMMARY

In our ENT department all pilot candidates have to perform the "Vestibular Adroitness Test" (VAT) published by Lansberg in 1954. It consists of bending the head once 60° downward and back to the upright position while being rotated at 180°/sec. This relatively mild coriolis stimulation of 703 candidates in 1978 caused no or very mild symptoms of motion sickness in 89% (Category I/II), pallor, cold sweating and mild nausea in 10.9% (Category III), and severe nausea with or without vomiting in 0.5% (Category IV/V).

In 1979 a selected group of 47 otherwise healthy young males met the strict criteria on the tilt table for orthostatic disorders. Their parameters of post-rotatory Nystagmus (ENG) were within normal limits. Contrary to the above mentioned pilot candidates, the incidence of motion sickness induced by the VAT was markedly higher; only 57% showed no or very mild symptoms of motion sickness, 26% pallor, cold sweating and mild nausea, but 17% experienced severe nausea with or without vomiting. There was no marked increase or decrease of blood pressure before and after the test. However, the categories differed markedly in their pulse rates: Category I/II average decrease of 1 beat/min., Category III increase of 6/min. and Category IV/V increase of 14/min.

In our ENT department all pilot candidates have to perform the "Vestibular Adroitness Test" (later referred to as VAT), published by LANSBERG in 1954 as a part of the initial physical examination. Procedure: Subject sitting head erect in a rotating chair, eyes open, with 10 rotations 180° per second clockwise, then bending the head forward 60° for 10 more rotations, moving the head back to upright position for 10 more rotations. Thus within 60 seconds all three semicircular canals are stimulated, causing a Coriolis sensation of tilting to the right when getting back from head-down to head-upright position. We cannot afford much stronger stimulations which would cause motion sickness in a larger portion of candidates, since they have to pass all other medical examinations the same day. When taking the head up from forward position we look for the tendency to tilt to the right (performance), which might extend from no tendency at all to falling uncontrollably against the right arm rest; in some rare instancies even short clonic seizures might occur. Moreover, we look for responses of the autonomous nervous system such as pallor, cold sweat and ask for symptoms of malaise. Considering these criteria the subjects are classified into five categories:

VAT Category	I	Very good performance, no vegetative symptoms
"	II	Good performance and/or moderate vegetative symptoms, no malaise
"	III	Tilting to the right, considerable pallor and cold sweat, moderate malaise
"	IV	Heavy tilting to the right, heavy cold sweat and pallor, severe malaise at the edge of vomiting, delayed recovery
"	V	Vomiting and nausea, very delayed recovery

A pilot candidate will not qualify for flying training if he has a history of recent motion sickness and belongs to VAT Categories IV and V; candidates with Category III are given a chance for basic training.

A comparative study on REACTIONS TO CORIOLIS STIMULATIONS AND POSTROTATORY ENG-RESPONSE published in 1974 by H. SCHERER and G. FRÖHLICH revealed, that parallel to the increasing susceptibility in motion sickness induced by the VAT there was a tendency towards higher values in all ENG parameters, but none of them was significant. In a further study we went through the medical record of this group of pilot candidates and looked for other parameters which might be relevant for the different responses to the same coriolis stimulation.

	Category I N = 30 age 21	Category IV/V N = 30 age 21,5
History of Motion Sickness	1 = 3 %	14 = 47 %
Hyperhydrosis	5 = 17 %	5 = 17 %
Tremor of Fingers, Chvostek, Dermographism	10 = 33 %	11 = 37 %
EEG: Signs of Circulatory Instability	2 = 7 %	3 = 10 %
Orthostatic Disorders	1 = 3 %	6 = 20 %
ENG: Maximal Slow Phase Velocity	62°/sec ± 22	75°/sec ± 26
Postrotatory Sensation	13 sec ± 9	24 sec ± 11

VAT Categories I and IV/V and different medical parameters

The only relevant differences between the VAT categories I and IV/V were: history of motion sickness 3% versus 47% and orthostatic disorders 3% versus 20%. This led us to the conclusion, that susceptibility to motion sickness and orthostatic disorders might derive partly from the same basic disposition of the autonomous nervous system to increased responses.
The relation of susceptibility to motion sickness and orthostatic disorders could be studied last year. There was a group of 47 otherwise young and healthy soldiers (average age 24 years) who all met the criteria for SYMPATHICOTONIC HYPOTENSION after MUTHESIUS: On the tilt table increased heart rates of at least 30/min. and decrease of systolic blood pressure of at least 10 mmHg. This is by far the most common form of orthostatic disorders in young males.
In this group of orthostatics we recorded history of motion sickness, postrotatory ENG and the VAT including heart rates and blood pressure before and after the Coriolis stimulation.

a) History of Motion Sickness Positive

VAT Category	none	in childhood	recent
I/II N=28	21=75 %	5 = 18 %	2 = 7 %
III N=11	5=46 %	4 = 36 %	2 = 18 %
IV/V N= 8	0	0	8 = 100 %

There is an increasing correlation between history of motion sickness and incidence of motion sickness in the VAT.

b) Table II: Absolute and relative frequencies of the three diagnostic categories of motion sickness in VAT for orthostatics and for the pilot candidates of 1978

	Orthostatics		Pilot Candidates	
	n	%	n	%
VAT I + II	27	57 %	628	89,3 %
VAT III	12	26 %	72	10.2 %
VAT IV/V	8	17 %	3	0.5 %

From these data we calculated a chi-square-test with pooled VAT Categories III and IV/V to have adequately large expected frequencies. The test revealed a very high difference betweenthe two samples ($p < 0.001$). We can conclude, that among orthostatics there are more subjects who get motion sick in the VAT than among a random sample of pilot candidates.

c) Postrotatory ENG Response

Table III

VAT Category		Total Amplitude (°)	Maximal Slow Phase Velocity °/sec.	Duration of Postrotatory Sensation (sec.)
I/II	n = 27	426 ± 211	45 ± 15	30 ± 15
III	n = 10	561 ± 139	65 ± 14	29 ± 14
IV/V	n = 8	518 ± 114	57 ± 12	26 ± 10

Total amplitude: The analysis of variance (Scheffé-test) revealed no significant difference ($0.5 < p$ 0.1) between groups I/II and III; there is only a certain tendency to higher values in groups III and IV/V.
Contrary to this the maximal slow phase velocities of group I/II versus group III as well as group I/II versus combined groups III-V revealed a significant difference on the o.o1 level.

d) Physical working capacity, blood pressure and heart rate

The physical working capacity 170 (PWC 170) is a measurement of the physical fitness derived from bicycle ergometry: the number of Watts necessary to obtain a heart rate of 170 beats per minute, divided by the subject's weight in kilogram.
Example: 200 Watts are necessary for an 80 kg subject to obtain a heartrate of 170/min: PWC 170 = 200 : 80 = 2,5. Normal range 2,5 - 3.5.

Table IV

VAT Category		PWC 170 (normal 2.5 - 3.5)	RR systolic (mmHg)	RR diastolic (mmHg)	Beats per minute Difference pre-post
I/II	n = 27	2,8	pre 120 ± 12 post 121 ± 8	pre 78 ± 8 post 81 ± 7	- 1.2 ± 9.6
III	n = 10	2,8	pre 127 ± 4 post 124 ± 12	pre 78 ± 5 post 76 ± 4	+ 4.8 ± 7.3
IV/V	n = 8	2,8	pre 118 ± 8 post 121 ± 11	pre 78 ± 7 post 77 ± 7	+ 13.5 ± 12.3

From this table we can state, that the three groups with no, moderate or severe motion sickness showed no difference in physical fitness, systolic and diastolic blood pressure. Contrary to this for the pre-post differences in heart rate the one-way analysis of variance revealed a significant increase ($p < 0.01$) from group I/II to groups III + IV/V.

From the study we can state that in young males with a symphaticotonic hypotension there is a high incidence of history of motion sickness, a high susceptibility to rather mild Coriolis stimulation and a tendency for increased heart rate with increasing motion sickness.

In a further study on recent data of 362 pilot candidates in 1979 we analyzed the interdependence of VAT-type, orthostatic-type and motion sicknes history. The frequencies and probabilities for the six categories are shown in the following table:

Table V

Category	Frequency	Probability
VAT I + II	334	0.92
VAT III + IV	28	0.08
Non-orthostatics	311	0.86
Orthostatic-type II	51	0.14
Negative history of motion sickness	331	0.91
Positive history of motion sickness	31	0.09

From these probabilities we calculated the expected frequency for each sub-category and compared the results with the obtained frequencies.

Table VI

Obtained and expected frequencies of pilot candidates regarding the diagnostic categories VAT, orthostatic disorders and history of motion sickness

		Obtained frequencies		Expected frequencies derived from Table V	
		VAT I/II	VAT III/IV	VAT I + II	VAT III + IV
Non-orthostatics	No History of Motion Sickness	272	11	262.4	22.0
	Positive History of Motion Sickness	21	7	24.6	2.1
Orthostatics	No History of Motion Sickness	40	8 17	43.0	3.6 6.0
	Positive History of Motion Sickness	1	2	4.0	0.3

In order to get adequately large expected frequencies we pooled three categories as shown in the table by dashed lines. The chi-square-test yielded a very significant difference ($p<0.001$) between obtained and expected frequencies. Therefore this study also confirms the hypothesis of an interdependence of either history of motion sickness or orthostatic disorders on one hand and a tendency of motion sickness in VAT on the other.

CONCLUSION

Coriolis stimulations of the same intensity and in the same psychological situation provoke very different effects in people with normal vestibular response. These responses may reach from no effects at all to severe motion sickness. It seems, that these differences partly depend upon the varying excitability of the autonomous nervous system, in this study represented by sympathicotonic hypotension on the tilt-table and the increase in pulse rate after mild Coriolis stimulation.
The predictive value of history of motion sickness is confirmed by the orthostatics group. In pilot candidates, incidence and history of motion sickness are much lower, which is partly due to dissimulation; on the other hand many young men with recent history of motion sickness will voluntarily refrain from becoming a pilot.

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DISCUSSION

GUEDRY

We have recently carried out a longitudinal study on 500 students who were given vestibular tests before beginning flight training. We have come up with significant correlations between test results and susceptibility to airsickness, though in our study the rate of rotation for Coriolis Stimulation was considerably lower than the 180^{o}/sec employed in your tests.

BENSON

Have you followed up, during flying training in the student aircrew with a low tolerance to the VAT and high susceptibility to motion sickness?

AUTHOR'S REPLY

This is now under way and is being carried out by a local Flight Surgeon. Initial results suggest that there is a correlation but there are exceptions. We cannot say that everyone who has a low tolerance to VAT will have persistent problems of air-sickness, but nevertheless I think the test will have predictive value.

BENSON

That is good to hear, but what is really needed is a test to exclude those student aircrew who are not going to adapt to the provocative motions of flight, rather than those who get sick on initial exposure but soon adapt.

AUTHOR'S REPLY

That is correct and is why we accept students with Cat.3. responses.

LÉGER

Have you measured the heart rate throughout your vestibular test? I ask this because we have studied the changes in heart rate during an 8 min provocative test which was very similar to the one you employed. We found that with the onset of early symptoms of motion sickness there is a bradycardia; it is only when the subject is close to vomiting that a tachycardia develops. I wonder, therefore, if you found any correlation between changes in heart rate during test and susceptibility to motion sickness?

AUTHOR'S REPLY

Our test was one of orthostatic tolerance rather than tolerance to provocative motion stimuli.

A GENERALIZED TRANSFER FUNCTION FOR DESCRIBING MECHANONEURAL SEMICIRCULAR-CANAL DYNAMICS[1]

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SUMMARY

Steinhausen's hypothesis, that a simple torsion-pendulum model adequately describes the dynamics of semicircular-canal action, has received its share of criticism. This is primarily because of the fact that the time courses of afferent discharges and vestibular reactions to angular-acceleration stimuli only approximately relate to the time course obtained as a solution to the torsion-pendulum model for the same angular accelerations. Thus, there is a need to determine a generalized transfer function which delineates those components that provide meaning to Steinhausen's hypothesis from those which describe other phenomena such as "adaptation".

INTRODUCTION

Rotational head movements stimulate the sensory end organs of the semicircular canals of the inner ear, causing compensatory eye movements (nystagmus), appropriate to the plane of rotation, via a vestibulo-ocular reflex arc. However, the sensory epithelia of the semicircular canals, the cristae ampullares, are relatively inaccessible for direct functional study during normal physiological head movements. In the first place, they lie deep within the skull, enclosed by spongy and petrous bone and the osseous labyrinth. Secondly, any technique which exposes the hair cells or their nerve supply for neurobiological experimentation necessarily disrupts the vascular supply to the neuroepithelium and interferes with the ionic balance between the perilymph and endolymph. Thirdly, even when the membranous ampullae are exposed, it is difficult to perceive the extent to which the normally invisible cupula covers the crista and fills the ampulla of the duct. (It is the cupula which couples the mechanical energy of head motion to the receptor hair cells of the crista for transduction into neural impulses at the afferent terminals.) Thus, it is not surprising that, for over a century, the dynamic response characteristics of the semicircular canals have not been completely elucidated despite continuous investigation by many vestibular physiologists.

Historically, until the time of Fluorens (13), the semicircular canals were associated with the perception of sound. By sectioning the membranous semicircular canals in the pigeon and the rabbit, Fluorens established that eye, head, and body movements always occur in the same plane as that of the injured canal. Goltz (16), also investigating the pigeon, first associated these canals with bodily equilibrium. Breuer (5), Crum Brown (9), and Mach (26) suggested that the cristae ampullares respond to rotatory accelerations of the head. Moreover, they also hypothesized that the motion of the endolymph within the canal was responsible for eliciting the neural activity in the nerve endings (hydrodynamic theory). (Mach, however, later appears to have favoured a hydrostatic theory, i.e., that pressure is the adequate stimulus--see refs. 19, 28.) Ewald (11), using an "hydraulic hammer", produced artificial endolymphatic movements in the canals of pigeons and demonstrated that the direction of head nystagmus was dependent upon the direction of endolymph flow. Ewald's "law" was placed on a firmer footing when Lowenstein and Sand (25) established that the action-potential (impulse) frequency in fibers innervating the cristae varied according to the direction of angular movement of the head.

In order to describe the dynamics of the semicircular-canal system, Steinhausen (36, 37), and, subsequently, Egmond, Groen and Jonkees (10), proposed the so-called torsion-pendulum model. In this model, the instantaneous angular deflection of the cupula, $\xi(t)$, caused by an instantaneous angular acceleration of the head, $\alpha(t)$, is governed by the linear differential equation

$$\Theta \frac{d^2\xi(t)}{dt^2} + \Pi \frac{d\xi(t)}{dt} + \Delta\xi(t) = \Psi\Theta\alpha(t), \tag{1}$$

where Θ is the effective moment of inertia of the endolymph in the semicircular canal; Π is the viscous damping moment per unit angular velocity of endolymph relative to the wall of the membranous canal; Δ is the elastic-restoring moment per unit angular displacement of the endolymph relative to the membranous ampullary walls; and Ψ is a constant of proportionality relating ratio volumetric displacements (between the cupula and the canal endolymph). The transfer function of Eq. (1) can be written as:

[1]DCIEM Publication 80-P-09

$$G_1(s) = \frac{\Xi(s)}{A(s)} = \frac{C}{(\tau_L s+1)(\tau_S s+1)}, \qquad (2)$$

where $A(s)$ and $\Xi(s)$ are Laplace transforms of $\alpha(t)$ and $\xi(t)$, respectively; $C = \Psi\, \tau_L\, \tau_S$; and $\tau_L \approx \Pi/\Delta$ and $\tau_S \approx \Theta/\Pi$ are the so-called long and short time constants of the heavily-damped cupula/endolymph system (10, 20).

One way to test the adequacy of this model is to record the neural activity of the primary afferent fibers innervating the semicircular canals as they respond to appropriate stimulation. This has been done for a variety of species of animals (2, 3, 12, 17, 18, 23, 24, 33, 34, 35, 38) and the model has been found to be deficient. The present set of experiments was designed to study the mechanoneural response characteristics of primary afferent, semicircular-canal units in the pigeon, in order to determine whether or not a generalized transfer function could be obtained which would also describe similar neurodynamics in other species. (In testing to this model, the assumption is made that the afferent activity is proportional to the cupular displacement.)

METHODS

White King pigeons (Columba livia) were surgically prepared for microelectrode recording from peripheral units which innervated the semicircular canals (primarily, the anterior semicircular canal). The animal (with head immobilized) was oriented on board a rotatory device so that the center of its head plane was coincident with the plane of rotation (according to the type of canal being recorded from).

The main rotatory sequence consisted of a series of sinusoidal angular accelerations,

$$\alpha(t) = \alpha_m \sin 2\pi f t, \qquad (3)$$

which were delivered to anesthetized preparations at frequencies, f, from 0.01 to 10 Hz with peak angular accelerations, α_m, of 2.0, 4.0, 8.0, 12.0, and 20.0 degrees/s^2 ($t \equiv$ real time in Eq. (3)). The single unit neural activity was amplified, displayed on an oscilloscope and recorded on magnetic tape according to conventional techniques. (One channel of the tape recorder was used for voice commentary; another for the stimulus reference signal.)

The stimulus reference signal was used to trigger a physiological signal analyzer (Nicolet Instruments Inc.) to count and store the taped, entrained action potentials in preselected appropriate time periods (bins) for up to 4096 sequential bins (see Fig. 1 for typical binned response). Fourier techniques were used on the binned neural data to obtain the magnitude of the peak amplitude of the response and the temporal (phase) relationship between the angular acceleratory stimulus and the fundamental component of the neural response.

Amplitude- and phase-values were used in a curve-fitting program on a PDP-11/40 minicomputer (Digital Equipment Corp.) to provide a distinct mathematical expression for the best-fitting transfer function for a linear system. (The steady-state frequency response for a linear system to a sinusoidal input angular acceleration may be found from gain,

$$|G(f)| = \{(\mathrm{Re}\, G(f))^2 + (\mathrm{Im}\, G(f))^2\}^{1/2}, \qquad (4)$$

and phase,

$$\Theta(f) = \tan^{-1} \{\mathrm{Im}\, G(f)/\mathrm{Re}\, G(f)\}, \qquad (5)$$

spectra (Bode plots--see ref. 30), where Re G(f) and Im G(f) are the real and imaginary parts of G(f), respectively.)

The method employs techniques in non-linear, least squares approximations and is applicable to both high- and low-order transfer functions (4). On the final interpolation in the program, the least squared error, LSE, of the best-fitting transfer function is obtained as

$$LSE = \tilde{Y}'Y, \qquad (6)$$

where Y is a residuals matrix ($\tilde{Y}' \equiv$ transpose of Y) which is made up of error terms that express the differences between the experimental data and the model which is to be fitted. The mean square error,

$$MSE = LSE/(2L - P), \qquad (7)$$

compares the goodness-of-fit of the derived transfer function to that of the experimental data ($2L \equiv$ number of real and imaginary components of the data points, and $P \equiv$ number of parameters in the transfer function).

A more detailed description of the methodology may be found in a special monograph (7) and elsewhere (6, 21).

RESULTS AND DISCUSSION

The simplest transfer function that fitted the data for all units is of the form,

$$G'(s) = \frac{Cs^k}{(\tau_L s+1)}, \tag{8}$$

where s^k is a fractional-order differential operator with $0 < k < 1$, and C is a gain constant with units in impulses$\cdot s^{-1}$/degrees$\cdot s^{-2}$ (21). The Bode plots for four of the units are shown in Figs. 2-5, together with their best-fitting G'(s), and the best-fitting torsion-pendulum model

$$G''(s) = \frac{C}{(\tau_L s+1)}. \tag{9}$$

(In Figs. 2-5, the effects of the τ_S = 2.0 ms (<u>vide</u> <u>infra</u>) contributes no more than 1% to the gain spectra between f = 0.01 and 10 Hz; consequently, the single-pole transfer function, G"(s), was an adequate representation of the torsion-pendulum model.) As is evident in the plots in Figs. 2-5, G'(s) is a much better fit to the data than is G"(s) (cf. the MSE values for the two models); and, in particular, the fit appears to improve with increasing k.

What, then, is the significance of k, or better still, s^k? Elsewhere, it is shown that

$$s^k = K \prod_{i=1}^{M} \left[\frac{D_i\ s\ (\zeta_{i-1}s+1)}{(\tau_i s+1)}\right], \tag{10}$$

where K and D_i are constants, M = ∞ (in theory, but finite when fitting Eq. (10) via a digital computer), and τ_i and ζ_{i-1} ($\zeta_0 \equiv 0$) are time constants (21). Interestingly, when M = 1, Eq. (10) becomes

$$s^k = \frac{KD_1}{\tau_1}\left[\frac{\tau_1 s}{\tau_1 s+1}\right], \tag{11}$$

which has previously been defined as the transfer function of the adaptation operator (27, 40). Thus, s^k appears to be a form of adaptation. Work by Thorson and Biederman-Thorson (39) suggests that s^k represents a distributed relaxation process which is inherent in the sensory-adaptation mechanics of <u>Limulus</u> photoreceptors, vertebrate retinal receptors, chemoreceptors, and other mechanoreceptors. Investigations by Taglietti, Rossi and Casella (38) further suggest that s^k likely represents a relaxation phenomenon consisting of a time-varying intracellular electrogenic process, the components of which are summed with the generator potential in the receptor hair cell.

The coefficient of variation, CV, was determined as the ratio of the standard deviation of intervals to the mean interval, as obtained from interspike-interval distributions of spontaneous single unit activity. When a regression of CV on k was made for 28 units, a statistically-significant product-moment correlation ($r = 0.384$, $P < 0.05$) was obtained (21). Thus, the larger the CV is, the larger the value of k and, consequently, the amount of adaptation. Other work by Goldberg and Fernandez (15), in squirrel monkeys, shows that the CV is statistically correlated with semicircular-canal afferent fiber conduction rates. The thicker fibers have faster conduction rates and larger CVs. Together, these findings suggest that sensory adaptation phenomena are directly dependent on the innervation pattern of the afferent fibers.

The transfer function, G'(s), differs also from that of G"(s) in that τ_L is not single-valued as it is in the torsion-pendulum model; rather, it is unit dependent, taking on values from τ_L = 4.45 to 22.17 s (mean $\pm$ SEM = 10.24 $\pm$ 1.20 s) (21). (In fitting Eq. (8), the coupling between k and τ_L would account for some of the five-fold range of values that were determined for τ_L. However, there is sufficient indication from other studies (32) that the response dynamics of small groups of contiguous hair cells are quite different from those of other groups.) Realizing that the hair-cell tufts are stiff (14), that their lengths vary according to their position on the sensory epithelium (crista) (22), that the number and thickness of the stereocilia can be variable (22), and that the mechanical properties of the cupula are not necessarily uniform across the crista (29), then it is plausible that τ_L could have a regional distribution.

The form

$$G(s) = \frac{Cs^k}{(\tau_L s+1)(\tau_S s+1)}, \tag{12}$$

or sometimes,

$$G(s)(\tau_m s+1) \tag{13}$$

was fitted to published afferent-response data in the squirrel monkey (<u>Saimiri</u> <u>sciureus</u>) (12), the frog (<u>Rana</u> <u>esculenta</u> and <u>R.</u> <u>temporaria</u>)(3), the gerbil (<u>Meriones</u> <u>unguiculatus</u>) (35), and the guitarfish (<u>Rhinobatos</u> <u>productus</u>) (33). The parameter $\tau_m \equiv$ high frequency time constant which results from both the displacement and the rate of displacement of the cupula. Such a term has been obtained from analysis of vestibular-driven eye movements in man (Benson and Sternfeld, cited in ref. 1), and primary afferent canal responses in the squirrel monkey (12) and the elasmobranch fish (24). Table 1 lists k, τ_L, τ_S, and τ_m for these four species and for unit responses to white-noise stimuli obtained from pigeons that were primarily encéphale isolé preparations. For all species listed in Table 1, the MSE using Eqs. (12) or (13) was comparable to or smaller than that obtained with other models. Further details are given elsewhere (8).

TABLE 1: Parameters of a generalized transfer function (Eqs. (12) or (13)) describing semicircular-canal dynamics in five selected species

Species	k	τ_L (s)	τ_S (ms)	τ_m (s)	Frequency range, f (Hz)
Squirrel monkey					
(a) "regular" units	0.06	5.60	3	-	0.0125-8
(b) "irregular" units	0.16	5.60	3	0.03	0.0125-8
Gerbil					
(a) CV ≤ 0.1	0.06	2.32	2	-	0.01-5
(b) CV > 0.1	0.26	3.67	2	-	0.01-5
Frog	0.16	5.60	-	-	0.0125-0.5
Guitarfish	0.50	1.99	-	-	0.02-4
Pigeon	0.24	10.24	2	-	0.5-16

In Table 1, the frequency range, f, was too restricted in the frog and guitarfish to utilize an adequate value of τ_S. In general, values of τ_S ($= \Theta/\Pi$) in the fits have been predetermined indirectly from the biophysical properties of the endolymph and the dimensions of the pertinent anatomical features of the membranous vestibular apparatus. The value $\tau_S = 2$ ms, which was determined biophysically by Money and colleagues (31) for the pigeon, suggests that there should be an upper break frequency ($f = 1/2\pi\tau_S$) of 80 Hz in the mechanoneural response dynamics in semicircular-canal afferents. Recording from canal afferents in the goldfish to stimulus frequency up to 70 Hz, Hartmann and Klinke (18) have given evidence that $5.70 \leq \tau_S \leq 7.82$ ms; values in the same range as those determined empirically for fitting to afferent data in other species (12, 21, 35).

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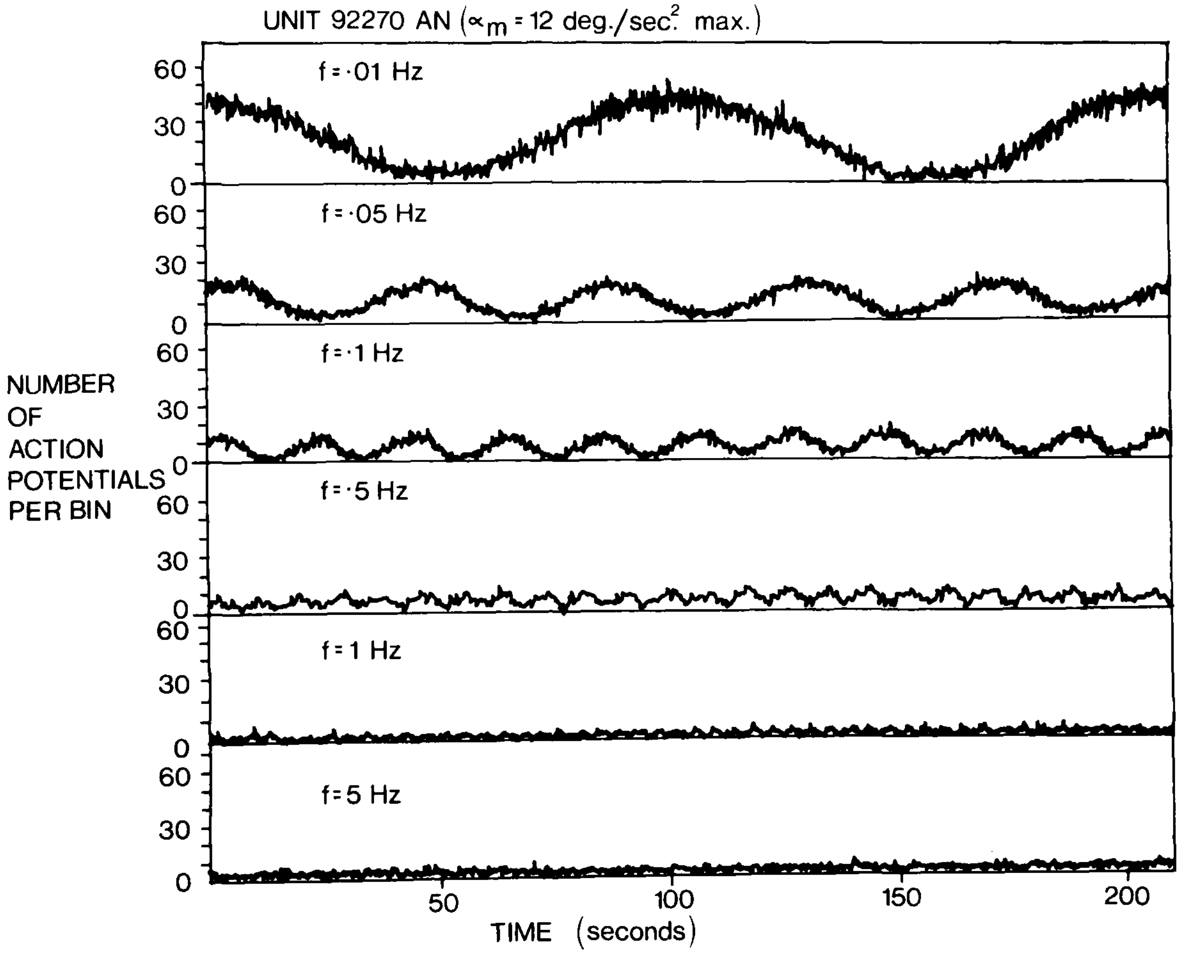

Fig. 1. Typical binned neural response. Bin widths are 0.2 (for f = 0.01 Hz), 0.1 (for f = 0.05 to 0.5 Hz), 0.05 (for f = 1.0 Hz), and 0.01 s (for f = 5 Hz).

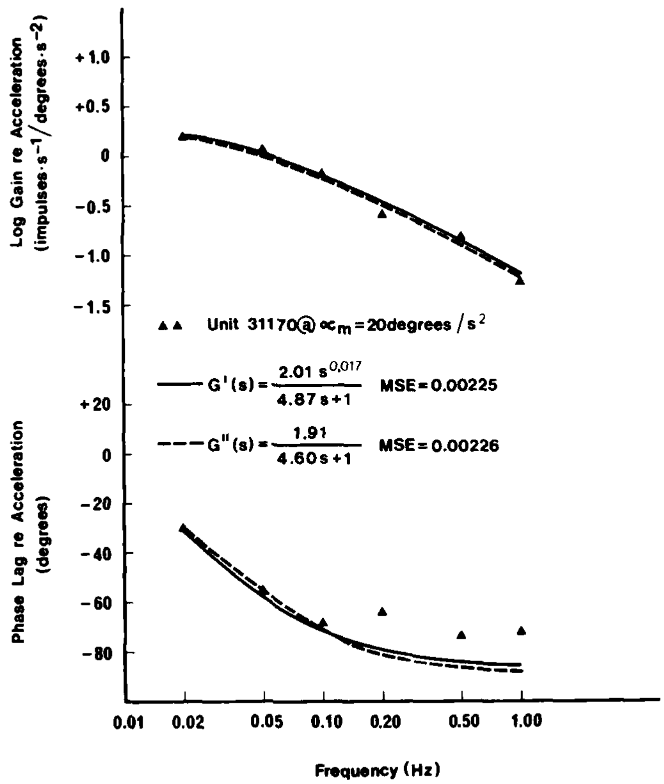

Fig. 2. Bode plot of Unit 31170 re angular acceleration and fits of models to data.

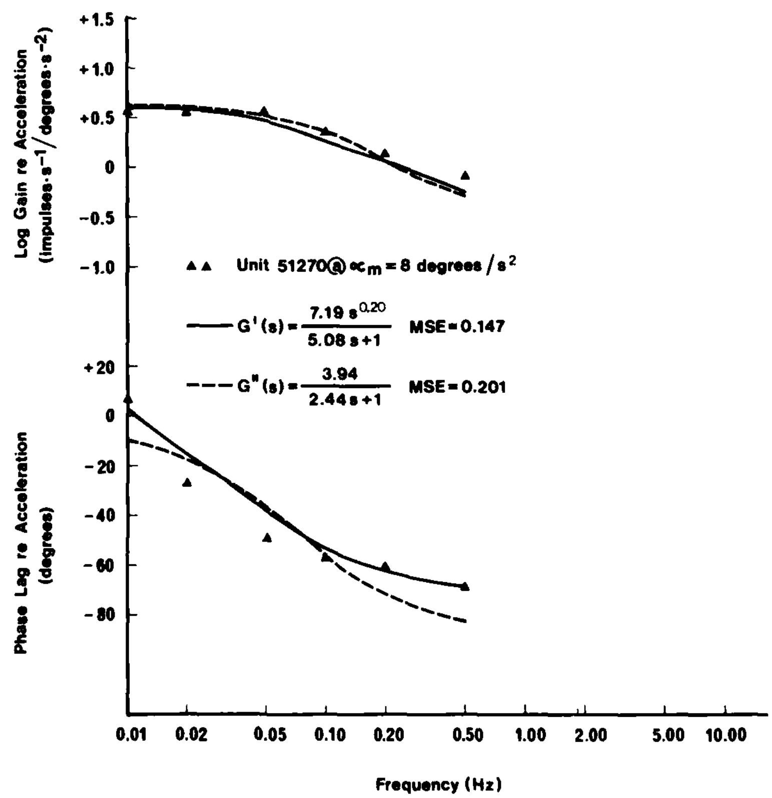

Fig. 3. Bode plot of Unit 51270 re angular acceleration and fits of models to data.

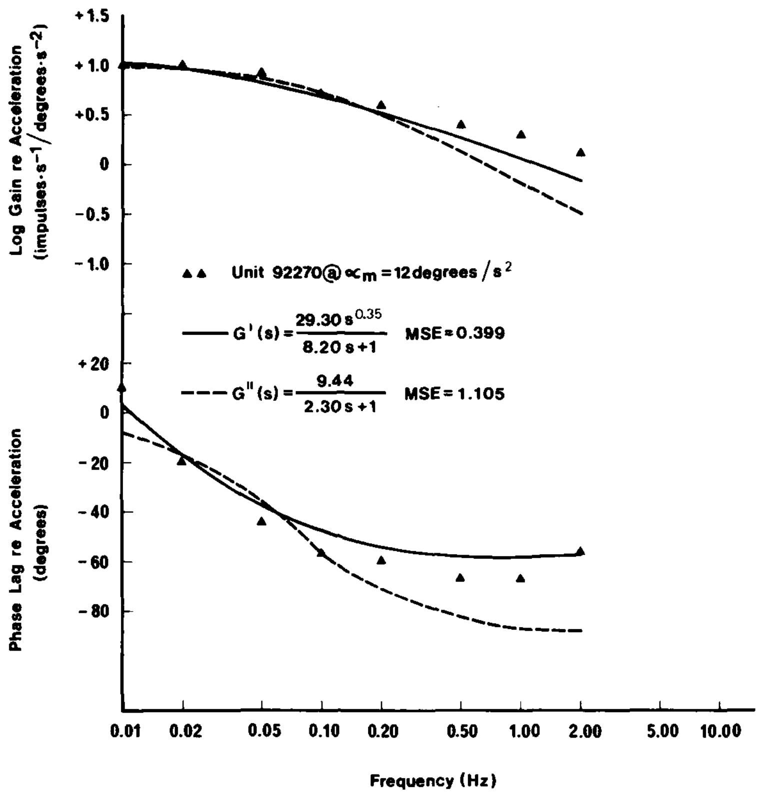

Fig. 4. Bode plot of Unit 92270 re angular acceleration and fits of models to data.

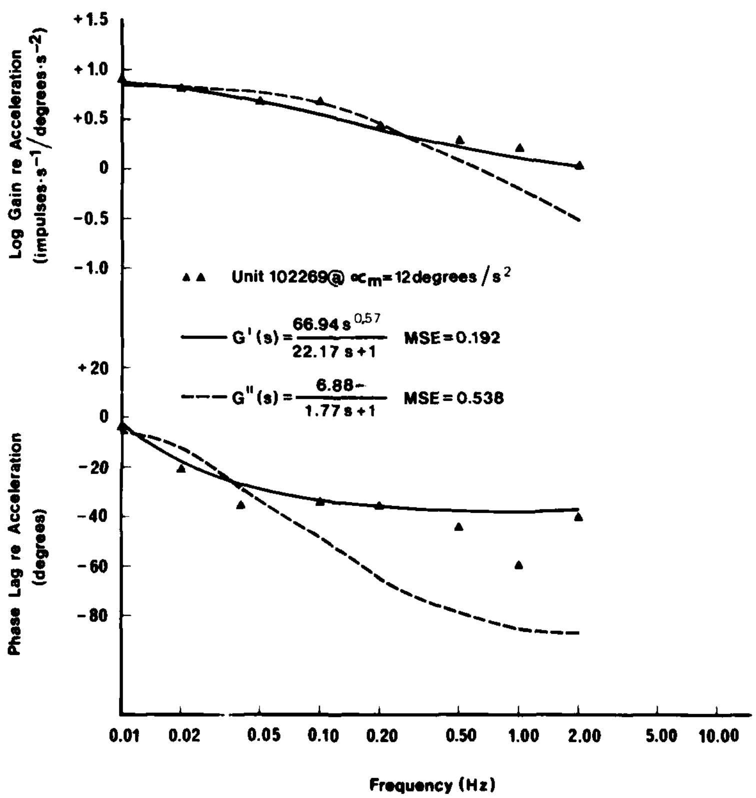

Fig. 5. Bode plot of Unit 102269 re angular acceleration and fits of models to data.

DISCUSSION

CLEMENT

In one of your slides I saw coherence function values as low as 0.45. If this is typical, is it still possible to treat the system as a linear system?

AUTHOR'S REPLY

Only one point had a coherence of 0.45, all the others were much higher and above the value of 0.75 which I consider to be good coherence and indicative of a linear system. This isolated point was at one extreme frequency, where a linear transfer function could be a dubious choice, but elsewhere a linear model proved to be adequate.

A MULTISTATION SPATIAL DISORIENTATION DEMONSTRATOR

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SUMMARY

An AGARD working group recommended (1) a number of measures to counter problems of aviator disorientation. One countermeasure proposed was the use of a rotational device capable of generating centripetal as well as pure angular acceleration and cross-coupled (angular) accelerations to provide a sequence of disorientation events to be used in conjunction with lectures designed to alert pilots to conditions that induce disorientation. Subsequently the RAF Institute of Aviation Medicine developed a single-station device that is regarded very favorably by pilots and student pilots after several years of use.

Under construction contract for the United States Navy is a multistation device (ten trainees) to demonstrate different classes of disorienting conditions. Some of these conditions are associated with unusual accelerative stimuli and some with subthreshold accelerative stimuli and reduced or misleading visual information including wide-angle visual field motions. The device also provides for demonstrating the beneficial effects of a good external visual reference and the disturbing effects on visual acuity of some visual-vestibular interactions. Recording and accumulating responses of trainees to permit well substantiated factual statements concerning the percentages of disorientation induced by each condition is another feature.

INTRODUCTION

This paper describes a disorientation familiarization trainer currently under construction for the U. S. Navy. The trainer is a small-radius centrifuge centered in a circular surround upon which moving or fixed visual scenes may be projected. It is designed for demonstrating a range of visual and acceleratory conditions that induce disorientation. Its purpose is to provide flight students with memorable personal experiences with various classes of disorienting conditions coupled with an introduction to disorientation-error prevention.

BACKGROUND

A time-tested approach to the reduction of accidents involves the application of safety and training programs. After a review of training practices employed in several NATO countries, an AGARD working group recommended a set of training measures aimed at reducing disorientation error accidents (1). Specific recommendations were made concerning a) lecture material, films, and visual aids; b) inflight demonstration of disorientation; and c) disorientation familiarization trainers. The report of the working group provided a review of current and past practices in connection with each recommendation, including a detailed comparison of the familiarization potential of various trainers (past, present, and future). Several problems were cited (1, p. 18) with disorientation training conveyed primarily by lectures and films that can be overcome by the use of a trainer:

> At the end of a "traditional" lecture on spatial disorientation, a proportion of the audience is likely to feel that the topic applies to a few susceptible unfortunates and is not of personal consequence (1,2), probably because perception of spatial orientation is considered to be psychological and hence controllable by "willpower." Instruction on equipment specific to overcoming disorientation is not presented in connection with the lecture. Thus, lectures do not attain the immediate relevance that is achieved in lectures on hypoxia in which the danger of oxygen deprivation and the utility of an oxygen mask in overcoming it can be demonstrated vividly. While flight instruments undoubtedly serve to avoid a large number of disorientation-error accidents (3, pp. 4-8), the principle focus of training on flight instruments is for important functions other than overcoming disorientation.
>
> Another deficiency of lecture and film material is the inability to convey to the audience the compelling nature of perceptual illusions involved in different forms of disorientation. A few minutes of well conceived demonstration are more valuable than many hours of lecture time, irrespective of the excellence of the lectures.
>
> Finally, there is, without doubt, variation in the quality and even accuracy of lectures as personnel change. Inaccuracies detected by students tend to reduce credibility. On the other hand, a well conceived demonstration is believable and memorable without commentary, and it can be accompanied by taped commentary, which can be as accurate as the current limits of knowledge. Moreover, it is likely that most events demonstrated will be vividly remembered and that they will be sufficiently interesting to generate discussion with the instructor and among classmates. In this way, the student can discover for himself that disorientation errors are normal responses under certain conditions.

Not long after the report of the AGARD working group was completed, the RAF Institute of Aviation Medicine developed a rotational device for familiarization training. As used initially in the RAF, one member of each training class was selected for a demonstration ride, but his classmates could observe the motion of the trainer while hearing the reports of the selected class member. Thus the classmates experienced the demonstration vicariously by observing the correspondence or lack of correspondence between the reported and the actual motions. Because of enthusiastic reception of this familiarization training device by pilots and student pilots (4), the RAF is now using two devices and a shortened demonstration time so that all student pilots can receive the familiarization training. The multistation device being developed for the U. S.

Navy and the planned demonstration time are designed to accommodate familiarization training of all aircrew in Navy flight training.

THE MULTISTATION DISORIENTATION DEMONSTRATOR (MSDD)

The multistation disorientation demonstrator under construction is a rotary platform with ten encapsulated stations (capsules) equally spaced on a concentric circle with a 2.44 m radius and designed to accommodate ten students per demonstration ride. Rotation at a radius is the only inexpensive way to generate sustained linear accelerations and controlled changes in linear and angular accelerations. Figure 1 is a plan view of the device.

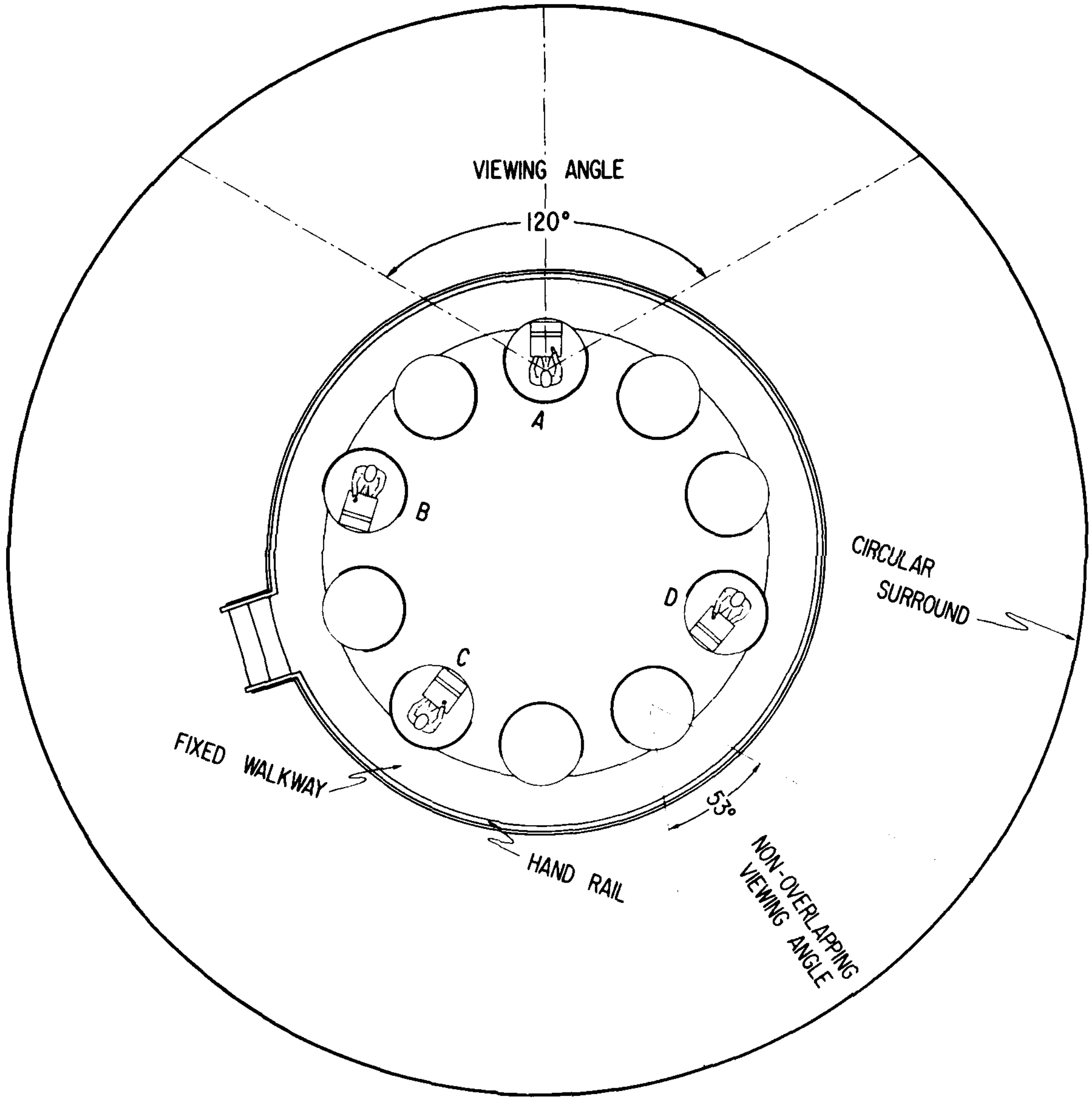

Figure 1. Plan view of MSDD and surrounding wall. Capsule headings referred to in text are illustrated: A - outboard (centrifugal); B - tangential; C - inboard (centripetal); D - intermediate. Capsule aperture provides horizontal visual angle of 120 degrees. For scenes not overlapping with those of neighboring capsules, horizontal visual angle is 53 degrees. Hinged side baffles on the headrest (not shown) may be manually positioned to yield reduced or full aperture width.

The rotary structure is surrounded by a concentric circular wall (6.86 m radius) for the display of stationary or moving visual images from a central overhead projection system consisting of a Xenon short arc lamp source which projects onto an eliptical reflector thence to a hyperbolic reflector and finally through a circular surrounding transparency onto the surrounding walls (Figure 2). Independently controlled rotation of the circular transparency permits moving or stationary displays on the circular surrounds. The drive system for the projected surround patterns must be capable of matching in real time the performance of the drive of the main rotary structure.

A viewport or aperture in each capsule can be opened to provide the student with a 120-degree view of the surround in the horizontal dimension (Figure 1) and a 40-degree view in the vertical dimension (Figure 2), but it can also be closed

to restrict vision to the interior of the capsule. Each of the capsules can be positioned in any of the headings illustrated in Figure 1 (or in any intermediate heading) at any time during the course of a demonstration run, although at any time in a run, all capsules will have the same heading relative to the main rotary structure.

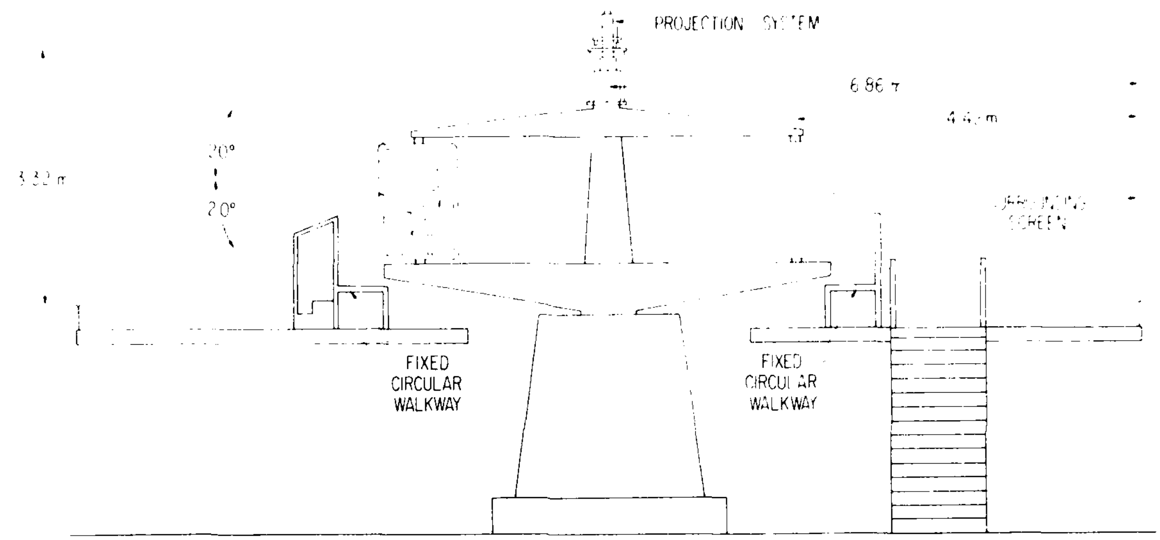

Figure 2. Elevation view of MSDD, illustrating 40-degree vertical visual scope, projector system, and dimensions of superstructure and surrounding screen.

The console within each capsule is depicted in Figure 3. It consists of a small, dim, blinking light, used in demonstration of autokinesis; four sets of small (height 3 mm) 5-digit LEDs and four response buttons, one corresponding to each set; four vertical columns of LED elements, two columns to set (with the control stick) a reference horizon while the device is stationary, and the other two columns for indicating (with the control stick) perceived horizons during different phases of the run. Position of the control stick will determine which pair of elements in these vertical columns is activated when this system is in use. Also displayed are two instruments, one an angular position indicator* and the other an angular velocity indicator. The three buttons on the lower face of the panel permit the student to signal perceived direction of turn and perceived stop, and on each side of the panel is a set of miniature thumbwheel switches displaying 5 digits which can be seen and adjusted to verbally commanded settings only when the head is tilted off-vertical through an angle of about 30 degrees. Activation of each of the instruments, interior and exterior lights, and digital displays is computer controlled by command signals from the operator's control room.

The planned drive for the main structure consists of two in-line DC torque motors. A closed-loop servo system will provide control of rotation characteristics as follows:

Maximum angular velocity = 120 deg/sec
Normal maximum operating velocity = 90 deg/sec
Maximum angular acceleration = 15 deg/sec^2
Operating angular acceleration range = 0.15 to 15 deg/sec^2

A smaller DC torque motor with comparable servo control will provide equivalent or better performance of the projection system.

Heading change of the individual capsules relative to the main structure will be accomplished smoothly by small DC shunt-wound motors, and once the commanded position is attained, capsule heading will be secured by magnetic brakes. Capsule heading as well as rotation of the main structure will be under control of command signals from the instructor's console and computer complex.

The computer complex will permit a single operator to select from a menu of programs that will control all aspects of the demonstration sequence including:

1) the time-dependent angular velocity profile of the main platform
2) changes in capsule heading at selected times during the profile
3) selection of motions and patterns projected to the surround by the projector system at selected times during the profile
4) opening and closing of the capsule shutter (Figure 4) at selected times during the profile
5) taped verbal instruction synchronized with various events during the profile
6) activation and deactivation of the student display lights and instruments at selected times in the profile.

- - - - - - - - - -

*The purpose of the angular position indicator is to provide a means of displaying with an instrument the turning motion of the MSDD; during rotation the student will see the continuous change in angular position whenever this instrument is activated.

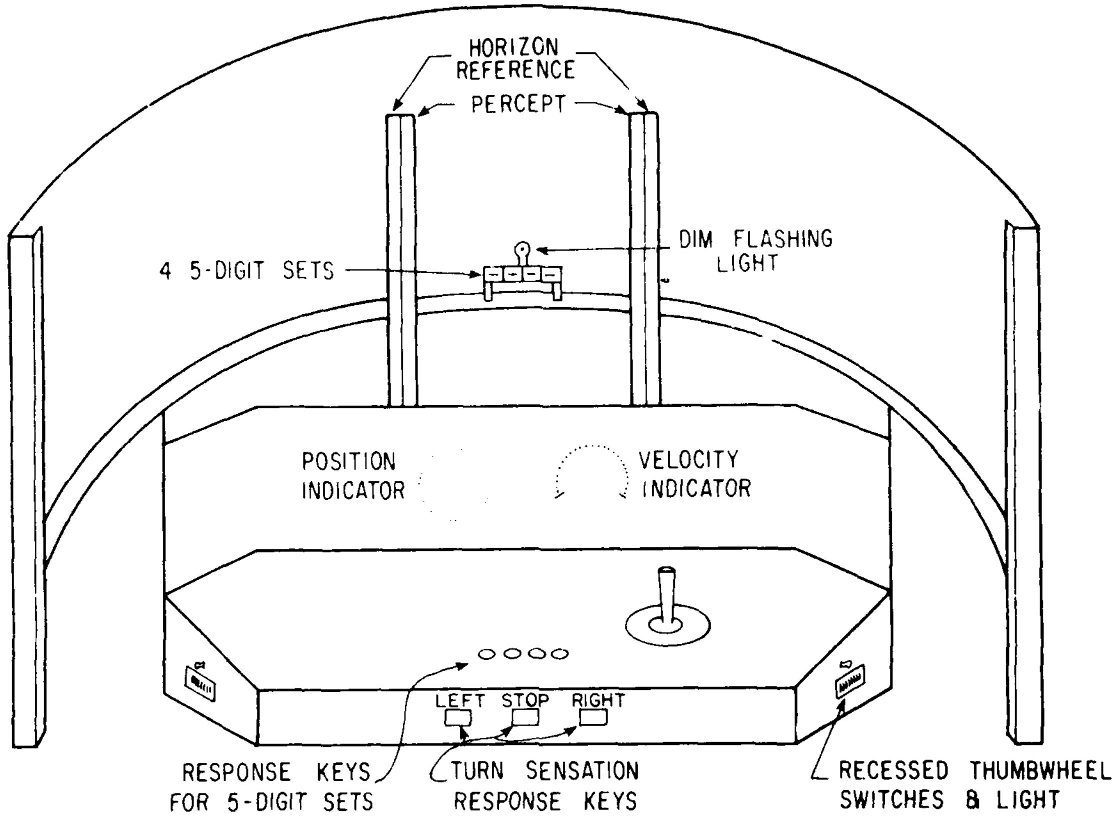

Figure 3. Console from student's viewpoint in capsule

In addition, the computer will be capable of storing and accumulating student responses to the various demonstrated events, thereby providing accurate and updated information on the probability of experiencing disorienting illusions under the conditions the student has just experienced.

PROJECTED USE

Presently it is planned to provide disorientation familiarization training to student pilots, student flight officers, student flight surgeons, aviation psychologists, and flight physiologists, but it is possible that all flight crew will receive training.

Several guiding principles for the application of this device as a familiarization trainer have been derived in part from the report of the AGARD working group (1):

1) A major objective of the demonstration is to show each student through his personal experience that disorientation is a normal response under a variety of conditions ranging from apparently benign circumstances, such as mere absence of normal orientation cues, to strong misleading sensory inputs. A second major objective is to give the student a demonstration that he will remember, along with an introduction to disorientation-error countermeasures.

2) Events demonstrated cannot simulate the combinations of linear [illegible] angular accelerations of actual flight maneuvers, and no such [illegible] should be introduced in the commentary. Rather, the demon- [illegible] show classes of orientation errors that frequently occur [illegible] the commentary will focus on circumstances in flight [illegible] different classes of orientation errors.

[illegible] accompanying the demonstration should be [illegible] should not introduce complex or lengthy ex- [illegible] would distract from the demonstration.

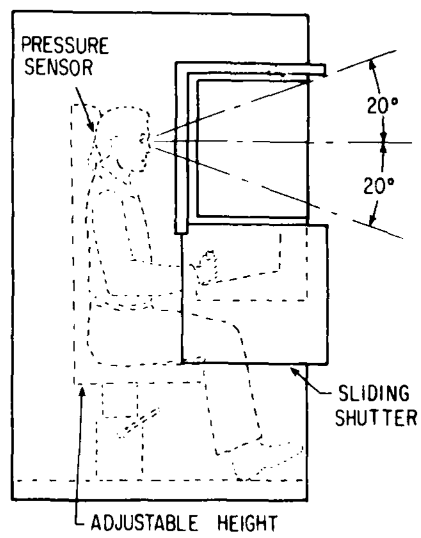

Figure 4. Side view of capsule, illustrating motorized sliding shutter for opening and closing the aperture. A spring produces upward force to seat which is locked in place by the hand lever under the seat when desired eye level is achieved.

However, expedience of presentation should not be an acceptable rationale for erroneous explanations.

4) *During the demonstration practical implications and operational causes of disorientation will be emphasized, with* only minimal reference to sensory mechanisms which can be better handled in a lecture. One function of the demonstration is to provide realism and relevance for any lecture on the topic.

5) When several disorienting events have been demonstrated and explained, brief instruction on dealing with disorientation in flight will be included. For example, the student will be required to set an apparent horizon during "steady state" exposure to a resultant force vector which is not aligned with gravity. This condition typically yields a setting which is displaced from the true horizon. Presenting the reference horizon to the student would reveal any error in his setting. The student will then be asked to bring his setting back into alignment with the reference. When accompanied by appropriate taped commentary, this can serve to demonstrate how flight instruments sometimes must be used to overcome disorientation in flight. This is in keeping with a specific recommendation by the AGARD working group, viz., that aircrew should not hear about disorientation and its potential consequences in flight without also receiving some instruction on how to deal with it.

6) The demonstration should be received early in training to lend relevance, interest, and realism to the lecture on disorientation and to generate alertness in the student concerning the occasional but important need to use flight instruments to avoid orientation error. Emphasis should be placed upon updating orientation information whenever visibility is low.

7) The demonstration will include a sequence of suggested motions, visual motions, and real motions that typically produce perceptual errors. Some of these motion conditions are nauseogenic. The nauseogenic conditions will be introduced toward the end of the demonstration, and the magnitude of the nauseogenic stimuli will be adjusted to avoid an unacceptable incidence of motion sickness.

A PROTOTYPE DEMONSTRATION SEQUENCE

While the training device under construction will permit selection from among a large number of programmed sequences, description of a particular prototype sequence may serve to provide the reader with a clearer concept of the planned familiarization trainer.

The training sequence will commence with demonstrations of autokinetic or autogyral effects (1) (apparent movement of a light or of light and body) and of visual circularvection effects (5-7). Autokinetic or autogyral effects will be potentiated by the use of a dim blinking light in complete darkness, by imparting brief motions to the main rotary structure during the introductory commentary to generate the expectation that motions might occur at any time, and by verbal instruction to signal the onset of perceived motions. Circularvection, the illusion of body movement generated by uniform motion in the peripheral visual field, will be enhanced by a task that requires ocular fixation of a fixed point in the capsule viewport, while a moving pattern projected onto the external surround is visible in the peripheral background. The trainer also permits projection, independently to each station, of large visual scenes (53 degrees x 40 degrees) containing realistic but tilted vertical and horizontal reference, thereby permitting demonstration of effects of scenes such as sloping cloud banks or tilted rays of sunlight on perceived attitude and on the setting of an apparent horizon. Following these visual effects, initiation of real movement at a subthreshold level will commence with shutters closed to reveal (by timely display of the angular position and angular velocity indicators) that substantial turn rates can occur with no better than chance detection. Then, by above-threshold deceleration to a lower constant rate of turn, students will experience and signal a sensation of turning in a direction opposite the actual direction of turn, and this illusion will be revealed by activating the angular position and angular velocity indicators. The same illusion will be elicited again by further deceleration to a stop while the indicators are being observed. Immediately upon stopping, opening the aperture of each capsule will reveal a fixed external surround that will abruptly terminate the false sense of turning, thereby demonstrating the powerful effect of a good external reference and, by contrast, the fact that symbolic instrument information, e.g., that provided by the position and velocity indicators, does not diminish perceptual illusions. Nevertheless, symbolic information of this kind can and must be used to override such illusions in order to maintain aircraft control during reduced visibility. This completes the first segment of the training sequence.

The important feature of this entire first segment is that a number of illusions of orientation will have been experienced and revealed without introduction of any strong acceleratory stimuli, and most will have been generated without introducing any acceleratory stimuli at all. This is important because many instances of disorientation in flight are more dependent upon the lack of orientation information via the visual sense or from visual misinformation than from any strong and unusual acceleratory forces. This early segment of the training sequence is designed to show the student that he and his classmates can be substantially disoriented under what seem to be benign and relatively smooth conditions, and hence that they must be prepared to update frequently their state of orientation from the symbolic information available on flight instruments whenever clear visibility of simple unambiguous terrain is limited. To demonstrate that symbolic information can be used in this way, the velocity and position indicators can be activated at appropriate times for those conditions in which the students erroneously perceive the direction of turn, and the reference horizon can be shown for the condition yielding errors in the perception of horizontality. In the latter situation the student can be instructed to bring his erroneous setting of the perceived horizon into alignment with the reference horizon, which will demonstrate how the symbolic information can be used to overcome a perceptual error.

The second phase or segment of the sequence will involve motion stimuli that are well above sensory threshold. At the commencement of this sequence, capsules will be facing outboard, the trainer will be stationary, and students will use the control stick to estimate the horizontal by controlling stacked LEDs in the outer two vertical columns, first in darkness and then with a realistic and accurate external horizon revealed through the aperture. This will demonstrate to the students that they can set a surprisingly accurate horizontal reference in darkness under static conditions without extraneous inputs.

The readjusted horizon setting when the external view is present will be used as the symbolic reference horizon against which subsequent judgments will be compared.

All capsules will then be positioned to face inboard and aperture shutters closed. In this configuration, angular acceleration to a turn rate of 60 deg/sec will be used to show that under some circumstances all students will correctly perceive the direction and even the approximate rate of turn, but that as the turn rate is sustained, this accurate perception will deliquesce to a sensation of zero turn rate even though a substantial rate of turn is still in progress. At this point, the inboard (centripetally) facing students (at a 2.44 m radius) will be experiencing a resultant force vector of only 1.04 g-units, but which is angularly displaced from gravity by 15.2 degrees. Under steady-state conditions of this kind, man tends to accept the direction of the resultant vector (i.e., the direction of his existing force field) as vertical, so that in this situation he would experience a "nose-up attitude." By manipulation of the control stick, which is now switched to control the innermost vertical columns of LED elements, the student will set his perceived horizon. This setting will be essentially level but displaced below the "true" horizon by about 15 degrees, as depicted in Figure 5. The perceptual error of this setting will then be revealed by retrieving from computer memory (and displaying) the previously determined horizon reference setting. The student can then be required to adjust the inner set of lights into alignment with the reference horizon and thus to correct a perceptual orientation error with symbolic information from an "artificial horizon." To provide some of the kinds of dynamic perceptual perturbations that occur during a flight adjustment, the capsule heading and/or centrifuge velocity could be altered while this alignment is being accomplished. For example, initiation of a capsule heading change toward a forward-facing (tangential) heading would introduce perceptual effects that the student would have to ignore during this alignment task, and the change would also serve to position the capsule for the next event to be demonstrated.

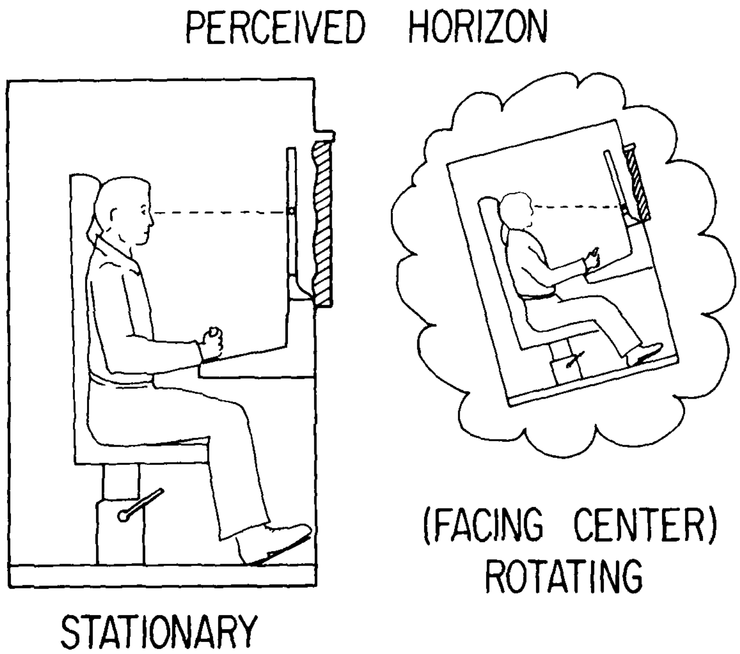

Figure 5. Illustrating the use of the control stick and vertical LED stacks in setting the perceived horizon.

By repositioning all capsules to a forward-facing tangential heading, students will be reoriented relative to the resultant force, and their perceptions will change from apparent nose-up attitude to a perceived lateral tilt. Under this condition, settings of the perceptual horizon will be rotated about 15 degrees relative to the true horizon, and this also can be revealed to students by retrieving and displaying the reference horizon. Again, students can be asked to adjust their setting of the perceptual horizon into alignment with the reference horizon to reinforce the idea that symbolic information can be readily used to correct orientation errors. At this time students will not correctly perceive their rate of turn, and by displaying the angular velocity and position indicators, this perceptual error will be revealed, thus conveniently introducing the idea that symbolic information from more than one instrument (horizon and turning indicators) must be combined to permit adequate control of flight and correction of orientation errors. With the trainer in this configuration, if the capsule apertures are opened to reveal a surround depicting a veridical realistic earth reference with the lead capsules in view, the erroneously perceived tilt, closely simulating "the leans," will be perceptually corrected. At this point it may be advantageous to comment on the tendency in mixed weather conditions to shift back and forth between instrument reference and earth reference, a practice which potentiates disorientation error.

Another 90-degree change of capsule heading, with centrifuge velocity still maintained at 60 deg/sec, will engender in the students a perceived 15-degree nose-down attitude as the capsules are positioned to face in an outboard (centrifugal) direction. Again a comparison of the perceptual horizon with the reference horizon will reveal an orientation error which is correctable by the use of symbolic instrument information. The student can then be shown the different settings that he has made of the perceptual horizon, one for each capsule heading, while the reference horizon remains displayed (see Figure 6). This sequential display of orientation errors, dependent upon reorientation relative to the existing force field, is a convenient introduction to commentary on the disturbing and strong disorientation that is apt to result from head movements in a high-g field, a phenomenon called the "g-excess effect" (8). This, in turn, can lead into the demonstration of

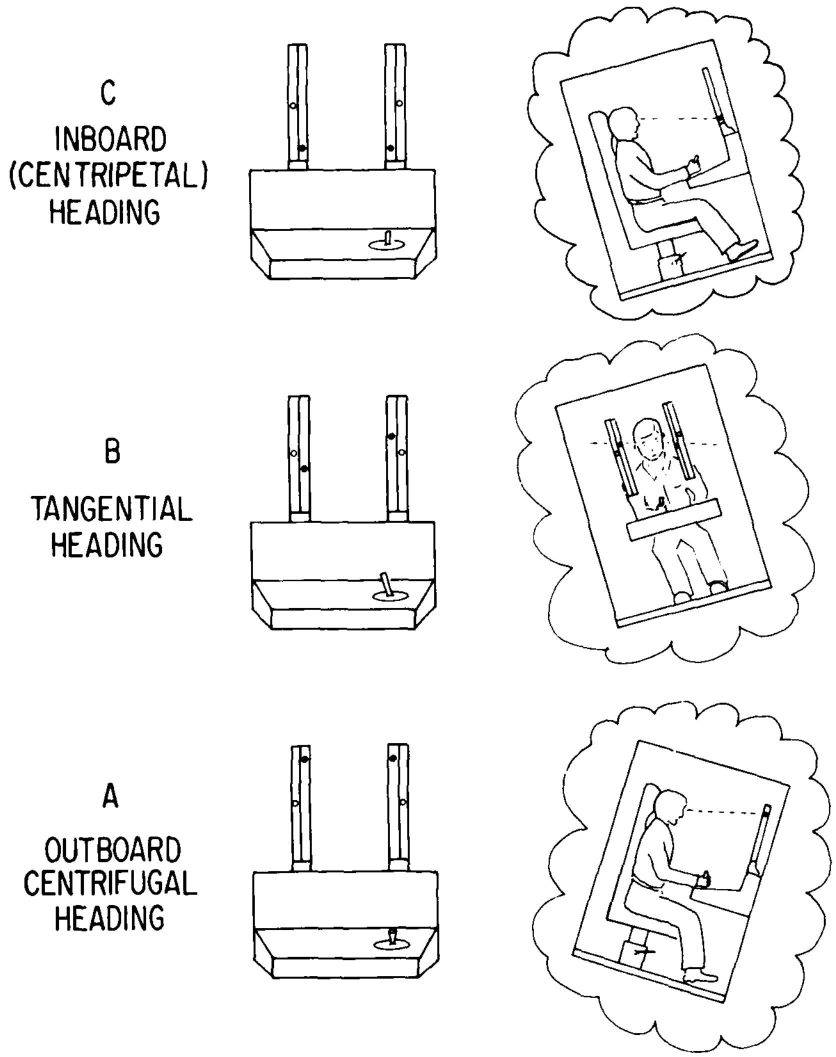

Figure 6. Illustrating typical settings of the perceptual horizon relative to the reference horizon in the three capsule headings described in the prototype demonstration sequence.

the similarly disturbing disorientation, sometimes called the "Coriolis effect," which is produced by head movements when an aircraft is in a fairly high-rate spin or turn. Instructions to dial in a 5-digit code with the miniature thumbwheels on either side of the console will require students to execute a head tilt of about 30 degrees to see one dial and then of 60 degrees to see the other. Thus the effect will be induced by requirement to perform a "cockpit task" as sometimes happens within aircraft during banks and turns. The headrest contains a pressure-sensing element that will detect departure and return of the head to the rest position. To illustrate the intimate relationship between external visual reference and inner ear responses to accelerative stimuli, the same head movements can then be repeated, but with the shutter open and with the students performing a task on the four 5-digit LED displays viewed against a veridical and realistic background. The disturbing disorientation from inner ear stimulation will be substantially reduced under these conditions of visual stimulation (9).

To complete the demonstration sequence, the angular velocity of the main structure will be increased to 90 deg/sec, with students continuing to perform a task with the four 5-digit displays. The task will simply be to continually signal, at a rate of 1 response/sec, which of the four 5-digit LED displays contains a prescribed digit. During acceleration to 90 deg/sec, visibility of the external reference will enhance the visibility of the 5-digit displays and will also tend to maintain the accuracy of the perceived motion and orientation. With aperture closure, however, a fairly steep ($\sim$ 31 degree) nose-down attitude will be perceived, though the total resultant force will be slightly less than 1.2 g-units. After one last perceptual horizon setting, the aperture will be opened and the task of digit detection within the four 5-digit displays will be resumed. Deceleration from 90 deg/sec to a stop at 15 deg/sec^2 tends to produce reflexive eye movements during the deceleration in a direction opposite the optokinetic reflexes engendered by the visible background. Under these circumstances, vision for "cockpit instruments" tends to blur, and the performance of tasks like digit-detection is degraded (10). This last demonstration in the sequence conveniently introduces the idea that exceptional spin conditions can engender reflexive responses to motion that may interfere with performance. The student, however, should be informed that recovery from sustained (multiturn) and fast spins is an unusual flight condition. It may be advantageous to note at this time that a number of drugs, and especially alcohol, greatly exacerbate the problem of maintaining clear vision during exposure to unusual motions (11).

The time estimated for this prototype demonstration sequence is ten minutes. A number of disorientation events will have been demonstrated, some of them several times for emphasis, along with mention of countermeasures. Students will

have received a memorable demonstration that they and their classmates can be disoriented and that disorientation is a normal reaction under certain conditions, but they will have also been given some appreciation of appropriate remedial actions and of things to avoid.

Our experience with a centrifuge only casually outfitted for this purpose is that such demonstrations provoke interest, curiosity, and heightened understanding of standard lectures on disorientation. There is also no reason why handouts or teaching machines should not be designed to answer penetrating questions from the interested student to any depth required by his level of interest and comprehension.

The experience of the RAF of the UK, now based upon thousands of users, is that this form of instruction is very favorably regarded by the student recipients as well as by experienced pilots and flight instructors. Because we have had excellent cooperation and information interchange with the RAF Institute of Aviation Medicine, we believe that the U. S. Navy trainer will incorporate all of the main elements of the RAF familiarization trainer and will add some new elements.

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DISCUSSION

LÉGER

I understand that the pattern of motion stimulation is designed in such a way as to avoid motion sickness. Do you have motion sickness problems in subjects aboard the device and, if so, what is the incidence of sickness?

AUTHOR'S REPLY

The device is still under construction so I cannot answer your question. However, Dr Benson has several years experience with a similar Spatial Disorientation Demonstrator and I believe the RAF have very little sickness during familiarisation training. However, they use a lower rotational speed during Coriolis stimulation than is planned for our device, so the incidence of sickness may be higher. On the other hand there may be some advantage in finding out who has low tolerance to motion stimuli as these people can sometimes be helped to overcome their disability.

LÉGER

Do you control the efficiency of your training and what are the criteria employed?

AUTHOR'S REPLY

We have had considerable experience of the kinds of tasks the cadets will perform during the 10 min demonstration, so we are confident that the sensations induced and task performance will be achieved with high reliability. Evaluation of the effectiveness of training, and, in particular, whether it will reduce disorientation accidents and incidents, is more difficult. Indeed, I don't think it is really feasible to carry out a long-term longitudinal study for conditions and criteria, of flying training, of operational duties and of aircraft type, are continually changing. I do believe the device will help aircrew to understand better the mechanisms of disorientation, as personal experience in such a device is a more effective method of teaching than lectures.

LANDOLT

What is the projected cost of the Multi-station Spatial Disorientation Demonstrator?

AUTHOR'S REPLY

I'm not sure that I should quote figures, but it is to be less than $1,000,000.

HAWKINS

Is there communication between instructor and student during the demonstration so that there can be individual instruction or 'feedback', or is the programme run from tape and all students hear the same commentary?

AUTHOR'S REPLY

The basic programme will be on tape but the design allows for communication between the instructor and an individual student, as well as between all students and the instructor.

SIMPSON

Do you plan to use the device to demonstrate to aircrew the adverse effect of alcohol on vestibular function and oculomotor control? I am concerned that, if such demonstrations are made in the device, the well controlled parameters of the device will give aircrew the impression that they can perform to a higher standard than might actually apply in flight.

AUTHOR'S REPLY

A specific demonstration of the effects of alcohol on vestibular function and the impairment of suppression of vestibular nystagmus is not included in the projected protocol for the device. The capability exists of demonstrating how a couple of social drinks can impair suppression and lead to blurring of vision during or after rotational stimulation; indeed, we have made effective demonstration in the laboratory using much smaller devices. Positional alcohol vertigo and nystagmus are more lasting phenomena, and are more difficult to demonstrate, as is their potentiation by increased G forces. At present, such a demonstration does not feature in the training sequence, but this could well be modified once we have practical experience of the device.

THE ROYAL AIR FORCE SPATIAL DISORIENTATION FAMILIARISATION DEVICE

by

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SUMMARY

The Spatial Disorientation Familiarisation Device (SDFD) was designed to demonstrate to aircrew the fallibility of their senses and the errors of perception that can lead to spatial disorientation in flight. The SDFD is a servo-controlled turntable on which the subject is seated, 1m from the axis of rotation, inside a light-tight cab. Displays within the cab show the subject that his sensations of rotation and attitude are in error, and permit the demonstration of oculogyral, oculogravic, cross-coupled (Coriolis) and autokinetic phenomena. Control of the velocity trajectory of the turntable and the illumination of the various displays may be pre-programmed and recorded along with a commentary on magnetic tape. This facility allows an optimised training sequence to be delivered consistently, even by relatively unskilled operators.

INTRODUCTION

Spatial disorientation in flight (i.e. a false perception of attitude, position or motion) has long been recognised as a major cause of loss of control in flight and hence of aircraft accidents. In the broadest terms, spatial disorientation occurs in flight because man's sensory system is adapted to transduce the angular and linear motion stimuli associated with normal locomotor activity on the surface of the earth, but in flight he is exposed to atypical patterns of angular and linear motion whose magnitude and time course may be outside the limited dynamic range of his sensory systems. Thus, on the one hand, he may fail to detect changes in aircraft orientation; on the other, the receptor system may provide false sensory cues and he may experience illusory perceptions of aircraft position,attitude and motion.

In order to minimise disorientation incidents and accidents it is generally accepted (1,7,8,12) that aircrew should receive formal training concerning the causes of spatial disorientation in flight, the various types of perceptual errors that constitute spatial disorientation, and how to cope with disorientation when it occurs in flight. Apart from lectures and films it is highly desirable that the instructional programme should include a convincing demonstration of the sensory limitations that are responsible for spatial disorientation. This didactic programme is most effective when the student experiences, for himself, the various perceptual illusions. He is then more likely to be convinced that his senses are fallible, and hence less likely to accept 'seat of the pants' sensations in the flight environment.

DESIGN PHILOSOPHY

Specifications of the SDFD were based on the requirements of the Royal Air Force Aviation Medicine Training Centre (AMTC), where the device would be used primarily for the 'Familiarisation Training' of student aircrew, though not exclusively, because experienced aircrew have to attend AMTC at regular intervals during their flying career for refresher training. Requirements considered to be important were that the SDFD should be:

(a) Capable of inducing and demonstrating, in a consistent manner, most of the common vestibular illusions and visual disturbances that cause or contribute to spatial disorientation in flight.

(b) Suitable for both classroom demonstration and for personal familiarisation training.

(c) Simple to operate, and have high reliability with minimal maintenance.

(d) Transportable.

Consideration of the relative advantages and disadvantages of the various rotational devices that had been developed as training aids (1) led to the conclusion that these requirements could be fulfilled by a device with only one degree of rotational freedom. It would have to be somewhat more complicated than a Bárány chair or the modified bar stool developed by the Federal Aviation Agency (8) but simpler than the 'trainer' with several degrees of angular freedom produced by the United States Air Force (9,10,11). The decision to employ a device with one vertical rotation axis (producing rotation of the subject in yaw) without provision of angular movement in pitch and/or roll, accords with the recommendation of the AGARD Working Group on Orientation/Disorientation Training of Flying Personnel (1). A second rotation axis would extend, slightly, the range of illusory phenomena that may be elicited, but the increase in cost, size and mechanical complexity was not considered to be commensurate with the small benefit to familiarisation training that would be achieved.

In drawing up the specification for the SDFD the decision was taken to optimise its role as a demonstrator of sensory limitations and illusions rather than as a 'trainer' which would modify perceptual motor responses. Controversy is not resolved over the concept that the ability of aircrew to cope with disorientation in flight will be enhanced by experience in a ground-based, closed-loop, device which has controls and instruments that simulate an aircraft. The principal objection is that such a device exposes the 'pilot' to angular and linear accelerations that, whilst disorientating him, are very different from those that occur in flight (1,12). Accordingly the cab, housing the subject, of the SDFD makes no pretence to simulate an aircraft cockpit or to distract him by provision of a flying task. Rather, he is required to attend to the sensations engendered by the motion stimuli and to compare these with correct information about the motion of the device that is presented from time to time. Conventional aircraft instruments could have been used to give heading and rate of turn information, though in the final design displays utilising light emitting

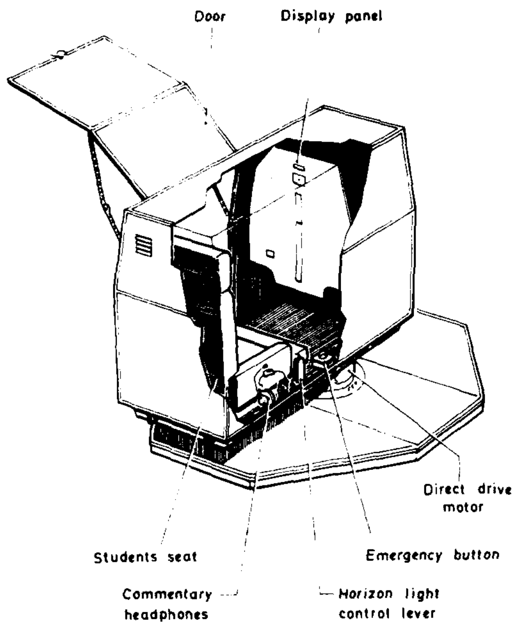

Fig 1. General view of the SDFD.

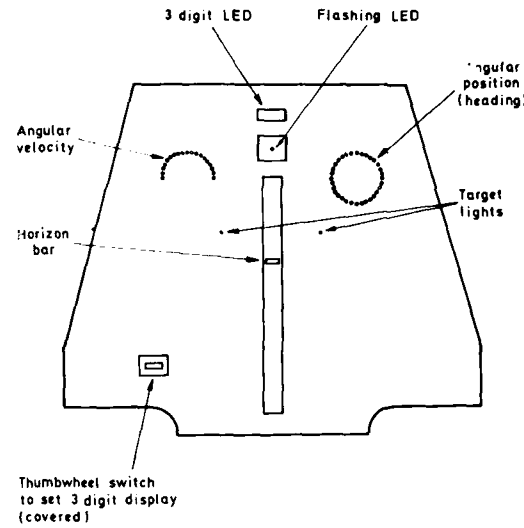

Fig 2. Subject's display panel. This is finished matt black. Angular velocity and position LEDs are yellow, all other LEDs are red.

diodes (LEDs) were chosen because of their higher reliability and ease of interfacing with SDFD electronics.

There is a wide choice of drive systems, capable of achieving controlled rotatory motion, but the need to produce angular motion stimuli which are below the threshold detection imposes severe constraints. It was, however, considered to be important that the SDFD should achieve sub-threshold angular accelerations without mechanical and auditory cues of motion, for a failure to detect aircraft motion and changes of attitude is a frequent cause of orientation error incidents and accidents (2). Evaluation of the various velocity control systems and drive mechanisms led to the specification of a DC torque motor directly coupled to the rotating structure of the SDFD. The elimination of any form of reduction gearing minimised spurious mechanical noise and gave a drive system requiring little maintenance with potentially high reliability.

DESCRIPTION OF THE SDFD

General configuration

Implementation of the specifications outlined above was carried out by the staff of the RAF Institute of Aviation Medicine, who were responsible for the design and construction of the mechanical and electrical systems of the SDFD.

In essence, the SDFD consists of a small cab (1.8 x 1.1 x 0.8m) mounted on an electrically driven turntable. A general view of the device is shown in fig 1. The octagonal base carries at its centre a housing for the DC torque motor, tachogenerator, electromagnetic brake and slip rings. The shaft, which is directly coupled to the torque motor, is supported on pre-loaded angular contact bearings and carries a lightweight platen, fabricated from aluminium alloy sheet and filled with polyurethane foam to increase its flexural rigidity. The subject's seat is mounted on the platen in such a position that the head of the subject is about 1.0m from the axis of rotation. Thus the device is, in effect, a short-armed centrifuge which permits some variation of the force environment experienced by the subject. The subject faces the centre of rotation and is able to view a panel upon which are mounted various displays (described below). The platen also carries a lightweight and lightproof cab fitted with a gull-wing door. The cab is ventilated by louvres and a small blower. The whole cab assembly is secured to the platen by four captive pins so that it may be detached easily for transportation.

The display panel (fig 2), which is mounted on a frame that may also be readily detached from the platen, carries several opto-electronic displays. These are illuminated, as required, by command signals from the operator's console. Two circular arrays of small light emitting diodes indicate the angular position and velocity of the cab; these are driven by electronic circuits receiving signals from a potentiometer and a tachogenerator directly coupled to the shaft of the motor. These displays are separated by the 'horizon bar' display which is an array of 128 rectangular LED elements. The position of the illuminated element is controlled by a small lever, fixed close to the seat, which the subject can operate to indicate the position of where he thinks the horizon would be if he could see out of the cab. In addition, the panel carries a small central LED of low intensity which flashes when switched on, and a pair of LEDs placed approximately at eye level are energised from a separate circuit. A small 3 digit, 7 element, numeric LED display (digit height = 6 mm) is mounted above the 'horizon bar' display; its thumbwheel control (used to set the display) is placed at the lower left hand side of the panel and is screened from the subject by a flip-up cover.

Communication between the operator and the subject is achieved by a conventional head-set and boom microphone. An emergency stop button is mounted in a readily accessible position to the right of the subject's seat.

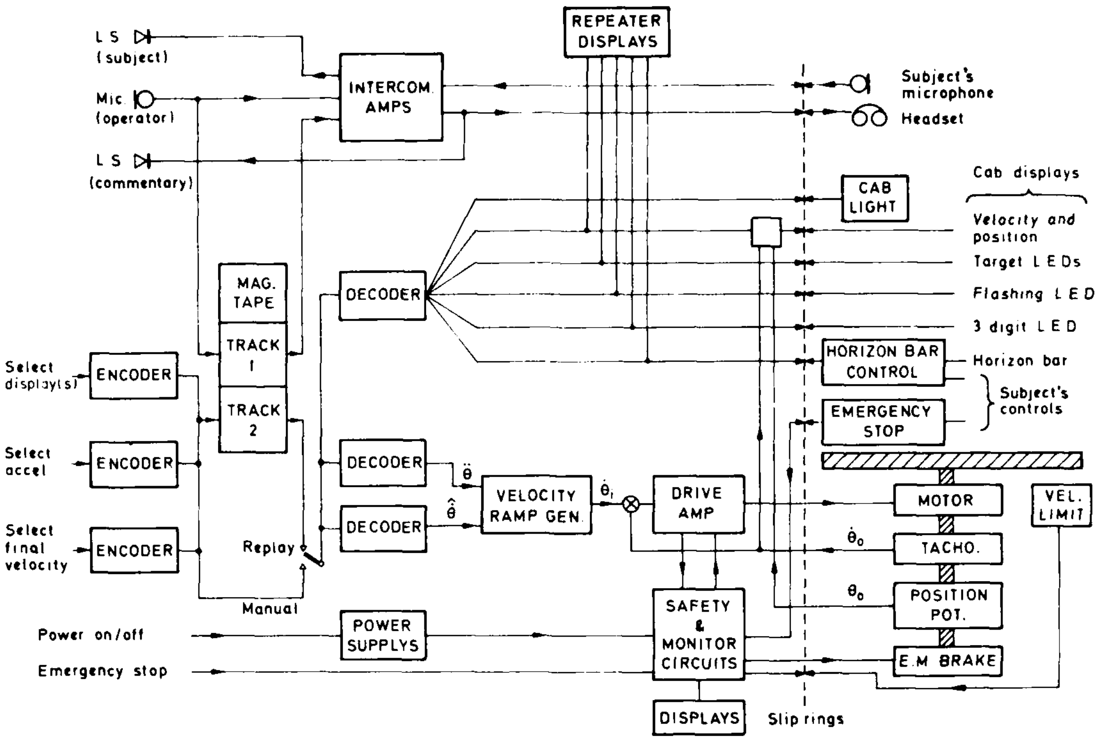

Fig 3. Block diagram of SDFD electronic systems.

Electrical Systems

Figure 3 shows, in simplified form, the configuration of the digital and analogue circuits that are employed in the SDFD. Rotation of the turntable is controlled by a velocity servo, utilising angular rate feedback from a direct-coupled tachogenerator. The motor (Inland Type T-10036) has a peak torque of 47 Nm (35 lb ft) which gives a maximum acceleration of the loaded cab of $18^{o}s^{-2}$ and a peak velocity of $180^{o}s^{-1}$ though the maximum speed during normal operation does not exceed $90^{o}s^{-1}$. The steady state velocity error of the control system is not greater than $\pm 0.2^{o}s^{-1}$.

The velocity demand signal to the motor control system is determined by the output of a ramp generator in which the slope, magnitude and polarity of the ramp are determined by two input voltages. In the original version of the SDFD these voltages were derived from two potentiometers, one of which allowed manual adjustment of the acceleration ($\ddot{\theta}$) (i.e. ramp slope) of the turntable, and the other determined the direction of rotation and the velocity ($\dot{\theta}$) at which acceleration fell abruptly to zero (i.e. ramp polarity and magnitude).

In the most recent version of the SDFD (as in fig 3) a more complex system is employed to derive $\dot{\theta}$ and $\ddot{\theta}$ control voltages, so that all control signals for both the drive system and the various displays can be recorded on magnetic tape. Thumbwheel switches on the operator's console are used to select the required acceleration (0.5 to $10^{o}s^{-2}$ by $0.5^{o}s^{-2}$ steps) and terminal velocity ($\pm 99^{o}s^{-1}$ by $1^{o}s^{-1}$ steps). Each setting is encoded in digital form before being passed to a tone burst generator which, in conjunction with other circuitry, transmits the encoded word in a bit-serial form that may be recorded on one track of a standard C60 cassette tape. On replaying the tape, the bit-serial data is converted to two bit-parallel words before the generation of analogue signals compatible with the circuitry of the velocity ramp generator.

Selection of one or more of the displays within the cab of SDFD is also achieved by a similar encoding and decoding system, the digital word being recorded on the same track of the cassette tape as the $\dot{\theta}$ and $\ddot{\theta}$ words. Although the system that had to be developed for the recording and replay of the various control functions is relatively complex it does not preclude direct operation from the console; the change from control by recorded tape to manual control may be made at any time by operation of a switch.

Communication between subject and operator is achieved by an 'open' boom microphone and head-set in the cab, and a 'press-to-talk' microphone and loudspeaker in the operator console. The operator is also provided with an additional audio circuit and loudspeaker that allows him to monitor the voice commentary recorded on one track of the cassette tape. During replay, communication between operator and subject is preserved, as on actuation of the operator's 'press-to-talk' switch the recorded commentary is overridden.

Safety Circuits. Protection of the subject and the electrical systems is ensured by a number of safety circuits. Operation of an emergency stop button in the cab or on the operator's console actuates a contacter which disconnects the drive amplifier from its power supply and puts the motor into a regenerative braking mode. A mercury filled switch, located towards the periphery of the platen so as to be sensitive to the radial acceleration, is employed on an over-speed trip which is quite independent of the feedback tachometer. Emergency stop is also initiated by electronic circuits which monitor: a) Motor current, b) Power amplifier temperature, c) DC supply rails, and d) Code parity of control signals on the cassette tape. Lamps on the

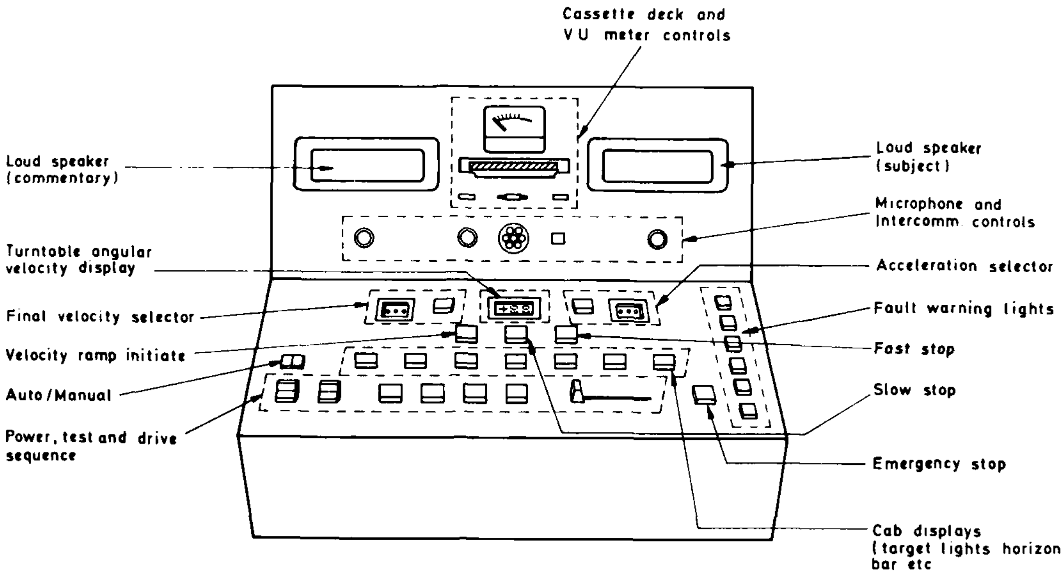

Fig 4. SDFD operator's console.

control console identify the safety circuit(s) responding to a fault condition.

Control Console

All operations of the SDFD and its displays are controlled from a small console (fig 4). The lowest row of switches and push-buttons energise the system (mains power on, DC power on, drive system energised, demand signal to control servo connected) and are interlocked by logic circuits to ensure operation in the correct sequence. The second row of illuminated push-buttons operate the displays within the cab (fig 2) as well as the cabin light. The push-button of the extreme left selects manual or automatic (i.e. tape controlled) operation of the SDFD. The controls and displays occupying the upper half of the lower console are concerned with the control and monitoring of the rotation of the SDFD. Thumbwheel switches are employed to set angular velocity and acceleration, though not until the adjacent 'go to' push buttons are pressed will the velocity ramp generator receive the $\dot{\theta}$ and $\ddot{\theta}$ signals appropriate to the pre-set values. Other push-buttons bring the device either to a controlled (i.e. at the pre-selected deceleration) stop, or to a rapid stop which utilises the electromagnetic disc brake and maximum reverse torque of the motor. The speed of rotation is indicated by a three digit LED display energised from the tachogenerator.

The vertically disposed indicator lights on the right hand side of the panel show the status of the safety circuits. These display the nature of a fault condition should the motor be de-energised as a result of a monitored system variable falling outside set limits or by a subject (or operator) initiated 'emergency stop'.

The rear panel carries the controls for the cassette recorder and the communication system. The cassette recorder can be operated in both record and play-back modes. Two tracks of a standard C60 cassette tape are employed, one to carry a spoken commentary, the other encoded signals which correspond in their control functions to the operation of the switches and push-buttons on the lower panel that determine the velocity trajectory of the SDFD and the selection of the display(s) presented to the subject. Also mounted on the rear panel are two loudspeakers and a microphone with ancillary control of the intercom system.

SENSORY LIMITATIONS AND ILLUSIONS DEMONSTRATED

The motion stimuli required to evoke illusory sensations of attitude and angular motion are well documented (1) and can be explained in terms of known physiological mechanisms of the vestibular and somatosensory systems. The stimulus conditions that have been found to give consistent results in the SDFD (i.e. specific illusions were experienced by all, or nearly all, subjects) are described in detail below. It should be recognised, however, that the velocity trajectory of the device is rarely critical and similar effects can be achieved with other stimulus profiles.

Illusions dependent upon semicircular canal function

i. Failure to detect rotation

With the cab in darkness and initially at rest, the subject is accelerated at $0.5^{o}s^{-2}$ to a speed of $30^{o}s^{-1}$. He is asked to report when the rotation is detected and the direction of the sensed motion. For some subjects this stimulus is below sensory threshold though, more typically, the motion is correctly detected after 10-30 sec. When steady velocity is achieved the velocity and position display is turned on to show the subject that his sensed rate of turn (which may be zero) is substantially less than the actual rate.

The use of a lower acceleration (0.1-$0.2^{o}s^{-2}$), which is below detection threshold for nearly all subjects (3,4,5) could have been employed, but the demonstration would then be time consuming; the choice of $0.5^{o}s^{-2}$ is an acceptable compromise when the time available for each familiarisation session is restricted.

Following the low level acceleration to $30^{o}s^{-1}$ the SDFD is accelerated at a supra-threshold rate of $10^{o}s^{-1}$. This increase in speed is readily detected by the subject and is confirmed by illumination of the display. Once at constant velocity, the cupulae of the lateral canals, stimulated by the preceding angular acceleration, slowly return to their neutral position and after about 20 sec the sensation of turning disappears. The failure to detect rotation at constant velocity is clearly demonstrated when the velocity and position display is switched on.

ii. Somatogyral and oculogyral illusions

These illusions are readily induced by a deceleration following a period of rotation at constant speed. For example, deceleration at $10^{o}s^{-1}$ from $60^{o}s^{-1}$ to $30^{o}s^{-1}$ gives rise to a consistently reported sensation of turning (a vertigo) in the opposite direction (the somatogyral illusion (2)). The associated oculogyral illusion (13) is manifest when the small target lights of the display are illuminated. These appear to rotate with the subject, when he feels that he is turning, and to be displaced in the direction of the sensed motion. The subject is made aware of the illusory nature of his sensations by showing him the position of velocity displays.

iii. Post-rotational sensations and nystagmus

Somatogyral and oculogyral illusions are also demonstrated when a rapid stop is made after rotating at a constant speed. However, when a high velocity ($90^{o}s^{-1}$) is employed in the SDFD, a strong nystagmus is elicited which cannot be suppressed by visual fixation for some 5 to 10 sec after the stopping stimulus.

The impairment of vision by the inappropriate nystagmus that accompanies the vertigo in the post-rotational period is demonstrated by asking the subject to read the small three digit LED display which is illuminated as soon as the SDFD has come to rest. The subject has no prior knowledge of the digits to be displayed as the number is changed by the operator before each subject enters the cab and the selector switch (located at the base of the display panel) is covered.

iv. Cross-coupled (Coriolis) stimulation

The disorientating sensations evoked by a head movement in one axis whilst rotating at constant speed about another axis can be very powerful and disturbing. The associated conflict of semicircular canal and otolithic cues may also precipitate the signs and symptoms of motion sickness. As the induction of motion sickness is likely to distract the subject and impair the effectiveness of the SDFD as a training aid, Coriolis phenomena are demonstrated at the relatively low velocity of $30^{o}s^{-1}$ and the number of head movements made by the subject is restricted. At this speed the sensation of movement in pitch induced by a head movement in the coronal plane (roll) (say, on moving the head from the left shoulder to the right), is generally mild and not perceived by all subjects. However, when the subject is presented with a couple of small target lights (7,8) a well defined oculogyral illusion is always detected. The lights appear to move up and down as the head is moved in roll, and when the head is moved in the sagittal (pitch) plane there is an apparent rotation in roll of the target lights.

Illusion dependent upon otolith (gravireceptor) function

i. Somatogravic and oculogravic illusion

These illusions are produced when the subject experiences an alteration of the force environment such that the resultant force vector is no longer aligned with the force of gravity. In the SDFD the subject's head is about 1m from the axis of rotation; therefore, when rotating at $90^{o}s^{-1}$ (1.57 rad s^{-1}) the radial acceleration is 2.5 ms^{-2} and the resultant vector has an inclination of 14^{o} to the gravitational vertical. With the subject facing inwards this force environment induces a sensation of backward tilt in the sagittal (pitch) plane - the somatogravic illusion - and an apparent upward movement of visual targets which have a fixed orientation with respect to the observer - the oculogravic illusion.

In the SDFD, the magnitude of the illusion is demonstrated by requiring the subject to position the illuminated element of the 'horizon bar' to "where the horizon would be if he could see out of the cab". Initial adjustment is made when the SDFD is stationary or at low velocity ($30^{o}s^{-1}$). The device is accelerated at $10^{o}s^{-1}$ to $90^{o}s^{-1}$ and the subject is told to position the illuminated bar to the perceived 'horizon'. Further adjustment is requested some 30 sec after the turntable has reached constant velocity, as it is known from laboratory (6) and flight experiments (14) that the oculogravic illusion takes a minute or more to develop fully, although it reaches about half its final amplitude within the first 10 sec following the change in direction of the force vector. Once the subject has made his final setting of the 'horizon bar' display the magnitude of the apparent change in pitch attitude is shown to him by the alternate illumination of two LED bars, one showing his original setting of the display, the other the final setting made when subjected to the modest radial acceleration. This alteration in the configuration of the display is controlled from the console, either by the operator or by a recorded encoded signal.

The demonstration is concluded by a rapid deceleration of the turntable. This stopping stimulus gives rise to a strong yawing vertigo, but in addition, the change in the force environment induces somato and oculogravic illusions. These are characterised by a sensation of pitching forward and a downward movement of visual targets as the radial acceleration decays. Some subjects also report a small transient lateral tilt and a rolling movement of the target lights caused by the tangential linear acceleration as the SDFD decelerates.

Visual Illusions

i. Oculogyral and Oculogravic Illusions

These are demonstrated in the manner described above.

ii. Autokinesis

The subject is told to look at a small LED of low luminance which is flashed, on and off, at about 1 Hz. All other displays are switched off, so in the light-proof cab only a small flashing light, centrally located on the display panel, is visible. With the cab stationary most subjects report apparent movement of the target light after 20-30 sec (i.e. visual-autokinesis) while occasionally illusory sensations of body movement and rotation (somato-autokinesis) are also experienced.

OPERATION AND UTILISATION OF THE SDFD

The particular way in which the subject is exposed to the various stimulus conditions that engender illusory sensations or, of no less importance, no sensations at all, is dependent upon a number of factors, as is the commentary that should accompany the demonstration. Notable amongst these factors are the experience and operational role of the aviator undergoing familiarisation training, the specific requirements of the instructor and the time available for familiarisation experience. Specific familiarisation programmes can be recorded on the cassette tape so that each subject may receive optimum familiarisation training. However, the SDFD may be operated under manual control at any time by switching from 'auto' (pre-recorded tape) to 'manual' control.

Since its introduction in October 1974, the SDFD programme has received wide acceptance (16) both from the instructors and the aircrew who have ridden the device. Also, it has been particularly gratifying to find that experienced aircrew commented favourably on the familiarisation training and were not infrequently surprised by the illusory sensations that were evoked by relatively mild rotational stimuli. An additional, and unanticipated, benefit of the SDFD was the way in which it stimulated aircrew to talk freely with their instructor and other course members about disorientation incidents which they had personally experienced in flight.

The initial (Mk I) SDFD was mechanically very similar to the Mk II version described in this report, but the cab displays were simpler and there was no record/replay facility. It was adequate for classroom demonstration in which the instructor operated the device and talked to the students who witnessed the behaviour and heard the verbal report of the subject in the cab of the SDFD. Unfortunately, only some 15% of the aircrew could be given personal experience in the SDFD because there was but one machine and the instructors had other commitments. However, with the development of the Mk II SDFD and the installation of two machines in 1978 at the Royal Air Force Aviation Medicine Training Establishment (AMTC) at North Luffenham, it has been possible to give all of the 1600-2000 a'rcrew, who have attended AMTC each year, individual familiarisation training in addition to the group demonstrations that are an established feature of the didactic programme.

The ability to record and replay a particular familiarisation programme has proved to be a great advantage and several cassette tapes have been produced. An example of a condensed SDFD programme is given in Annex A. The tape runs for about 6 min and during this time the full capability of the SDFD is exercised.

CONCLUSION

The SDFD plays an important role in the ground-based education of aircrew concerning the problems of spatial disorientation in flight, as it provides tangible expression of lecture material which is further reinforced by the personal experience of the student. In this way the aviator is made more aware of the type of perceptual disturbances that occur in flight and so he is better equipped to recognise spatial disorientation in the flight environment and is less likely to allow his control of the aircraft to be based on erroneous or inadequate cues. The SDFD is thus a contribution to flight safety.

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ANNEX A

AN EXAMPLE OF A CONDENSED FAMILIARISATION PROGRAMME

Panel (Push Button) Operation	Cab Status	Commentary
* Select ω_1 = R. $30^o s^{-1}$ and Enter α = $10.5^o s^{-1}$	Starting condition: Cab light on Cab stationary	Over the next few minutes I want to show you some of the ways that the senses may be fooled by unusual visual and motion stimuli. Illusions of the type to be demonstrated also occur in flight and are the cause of errors in the perception of aircraft attitude and motion - that is spatial disorientation - in flight.
Cab light off	Cab light extinguished	I'll now put the cab lights out and bring up two displays. The one on the left shows speed and direction of rotation and the one on the right angular position - like a compass.
Display (position & velocity) on	Position & velocity displays illuminated	
Go to ω_1 Go to ω_o	Cab accelerates to R $30^o s^{-2}$ and stops at 10.5^o s^{-2}	You may see how they operate when I rotate you to the right and stop.
Select ω_1 = L. $30^o s^{-1}$ Go to ω_1 Go to ω_o	Cab accelerates L $30^o s^{-1}$ and stops at $10.5^o s^{-2}$	And now turn to the left and stop.
Display off	Position & velocity displays extinguished	I'll put the display off and ask you to look at the flashing light in the centre of the panel.
Flashing light on	Small flashing light illuminated	
Select ω_1 = R. $30^o s^{-1}$ and enter		What do you see? (Pause 20 sec)
Cab light on Cab light off	Cab light on Cab light off	You may have thought that the light was moving, but when the cab light is switched on you'll see that it was stationary.
Go to ω_1	Cab acceleration to R $30^o s^{-1}$ at $0.5^o s^{-2}$	This illusion - the autokinetic illusion - can be a cause of disorientation when flying at night. Aircrew can think that a small fixed light on the ground is moving and perhaps go chasing after it under the erroneous impression that it is a light of another aircraft. It can also be a further problem when attempting to land or maintain hover in a helicopter at night when the only visual reference for the pilot is an isolated light. Now during the commentary the cab has been slowly accelerating. Do you know which way you are turning and how fast you're going?
Display on	Position & velocity display illuminating (Cab still accelerating)	Here come the velocity and position displays so that you can see what the motion really is.
	Cab velocity $30^o s^{-1}$	You're now rotating at 30^o/sec to right.
Display off	Position & velocity display off	That was a low level of acceleration close to the threshold of perception.
Select ω_1 = R. $60^o s^{-1}$ and enter α = $10.5^o s^{-2}$	Cab accelerates to $60^o s^{-1}$ at $10.5^o s^{-2}$	I'll now give you a stronger stimulus which you should be able to detect easily.
Display on Display off	Position & velocity display on " " " " off Cab at $60^o s^{-1}$	Yes - you're going to the right again - as you may see. What's happening now? Do you think the turntable is slowing down?
Display on Display off Enter	Position & velocity display on " " " " off	This is not so, you're rotating at a steady speed. This is just another limitation of our sensory system. Without vision we cannot detect movement at constant velocity.
Select ω_1 = R. $30^o s^{-1}$ and enter	Cab decelerates to $30^o s^{-1}$ at $10.5^o s^{-2}$	I'll change the speed. What do you feel? Rotating to the left?
Display on Display off	Display on Display off	No that's not correct, you are still rotating to the right but at a slower speed. This is the somatogyral illusion.

* ω_1 is terminal velocity and α is acceleration, as determined by thumbwheel switches and initiated by the 'go to' command.

ω_o is a zero velocity demand.

Panel (Push Button) Operation	Cab Status	Commentary
	Cab at $30^{o}s^{-1}$	We'll stay at this speed of 30^{o}/sec and try the effect of head movement - but wait a moment. When I tell you, I want you to move your head in roll from the upright to the right shoulder and keep it there.
Target lights on Target lights off	2 small target lights illuminated. Target lights off	Notice what happens to the two target lights on the panel. OK - move your head now. Keep it in that position. Now move your head to your left shoulder. Keep it there. What did you notice? Did the lights appear to move up, the first time you moved your head and down when you moved it to the left. You may have also felt some tumbling sensations too. Bring your head to the upright. Notice anything this time? What you should have experienced are illusions due to cross-coupled or Coriolis stimulation of the semicircular canals. Head movements when made in an aircraft which is turning can be a potent cause of disorientation.
Horizon bar on Select $\omega_1 = R.\ 90^{o}s^{-1}$ Cab lights on Cab lights off	Horizon bar illuminated Cab lights on Cab lights off	I'll now put on the horizon bar display. The switch to the right of the seat controls the position of the light bar. Would you now set the position of the bar to where you think the horizon would be if you could see out of the cab.
Horizon bar off Enter ω_1	Horizon bar off Cab accelerates to R 90^{o}/sec at $10.5^{o}/sec^2$	OK, that's good. I'll now wind up the speed to give you a little radial acceleration - ¼ 'g' to be precise.
Horizon bar on	Horizon bar illuminated	You've now reached operating speed. Would you adjust the bar to indicate the horizon again (Pause 20-30 sec). Any further adjustments required? (Pause 10 sec).
Initial horizon on	Horizon bar display flashes between initial and last setting	OK then, I'll show you your initial setting of the horizon bar so that you may compare it with your last setting under 'g'. You will have probably set the bar low, which indicates that you have a false sensation of a nose up attitude - the somatogravic illusion.
Horizon bar off	Horizon bar extinguished	Shortly I will stop the rotation. Try and read the little number display at top centre which will come on shortly after stopping. Also notice any apparent change in attitude that occurs as the 'g' comes off.
Rapid stop Number display on Display on Number display off	Cab decelerates to stop at max rate. Number display illuminated Position & velocity display on Number display extinguished	(Pause 10 sec) You have been stationary for 10 sec but you probably still feel as if you're turning - the somatogyral illusion again - even though the display shows that you have stopped turning.
Position & velocity display off	Display extinguished	Before you unstrap and leave the cab, remember that illusions - false sensations - such as you have just experienced, can and do occur in flight. Man's senses - your senses - are not perfect. So remember - whenever you fly without adequate external visual cues, rely on your instruments to determine aircraft orientation and, believe your instruments, not the seat of your pants.
Cab lights on	Cab illuminated	Thank you. Please unstrap and leave the cab.

DISCUSSION

DE HEYN

How often do aircrew receive refresher training on spatial disorientation and related sensory limitations in flight?

AUTHOR'S REPLY

Operational aircrew are given refresher training in Aviation Medicine, which of course includes discussion of spatial disorientation and allied problems, at intervals not exceeding 3 years. Flying personnel receive additional training in Aviation Medicine when they pass from advanced Flying Training to their Operational Conversion Unit, when they transfer from one type of aircraft to another and when they return to flying duties after a ground tour.

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14. Abstract

The importance of spatial disorientation as a cause of aircraft accidents was last addressed by the Aerospace Medical Panel in 1971. In the years since then, there have been developments and changes in operational roles, aircraft instrumentation, and in aircrew training which are likely to have had an impact on the aetiology and incidence of spatial disorientation, and the Panel considered it timely to again discuss the topic.

The eleven papers presented by experts in the field discuss not only the contemporary problems and causal mechanisms but also the measures that are available to minimise loss of life and aircraft because of spatial disorientation.

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